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SPACECRAFT PRELIMINARY ABORT AND ALTERNATE MISSION STUDIES FOR AS-504A

VOLUME III - LM ABORT AND CSM RESCUE DURING THE LUNAR ORBIT PHASE

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SUMMARY

Preliminary recommendations and supplementary data are presented for LM abort and CSM rescue rendezvous procedures for the lunar orbit phase of the lunar landing mission. These procedures are based on total propulsion activity by either the LM or CSM, although a discussion of combined LM and CSM activity is included.

The lunar orbit phase is divided into three subphases: Hohmann descent, powered descent, and ascent from surface. For each subphase, recommendations for non-time-critical and time-critical procedures and associated data are presented for both LM aborts and CSM rescues. For the extremely complex (presently not thoroughly investigated) area of LM anytime lift-off from the lunar surface, only maximum and constrained parameter capabilities are presented.

Onboard solution sequences apply totally for most of the procedures and for all but the initial maneuvers for the procedures initiated by external maneuvers. Maximum MSFN backup capability is also incorporated where possible.

The ΔV budgets and LM lifetimes reflect current average values. The propulsion system used is not specified for each maneuver, since the system used is dependent on the situation; however, preferred systems for a given situation are indicated.

For aborts prior to LM landing, the recommended non-time-critical procedures are relatively straight forward and sufficiently defined. The time duration and ΔV requirements for non-time-critical aborts are well within the capabilities of the vehicles. Most of the recommended time-critical procedures for all phases necessarily involve critical parameters and relatively high ΔV requirements.

The lift-off times for the ontime LM ascent and for the most operationally desirable CSM rescue are approximately the same time, and the in-orbit ΔV requirements are essentially equal.

The use of combined LM and CSM activity is probable for many of the time-critical situations and for non-time-critical, anytime lift-offs when the CSM is more than about 150° ahead or 100° behind at LM lift-off. Theoretically, however, for absolute maximum "LM-alone" capability, there are no lift-off phasings which require CSM assists when the in-orbit plane change requirement is less than approximately 0.2°.

If the LM has no propulsion system available after obtaining the standard orbit of 30 by 10 n. mi., an anytime lift-off phasing gap exists for which CSM rescue is not possible within the maximum capabilities of LM lifetime and ΔV rescue budget. This gap extends from the CSM directly above the LM to approximately 70° behind the LM at LM lift-off.

The CSM rescue procedures, except for the few involving only direct intercept, require maneuver information from the LM or the MSFN, since the CSM onboard computer contains only the direct intercept rendezvous sequence. Essentially all of these CSM rescue procedures involve terminal approach from above.

INTRODUCTION

This report presents the Mission Planning and Analysis Division's preliminary recommendations for abort and rescue procedures for the separated LM-CSM portion of the lunar orbit phase of the first Apollo lunar landing mission.

The objective is to recommend the rendezvous procedure to use when an abort or rescue is required, not to define abort and rescue criteria. The "why" of an abort or rescue is considered only when it directly affects the rendezvous procedure.

The majority of the recommended procedures are generalized and apply to a range of times or phase angles instead of only one specific time or phase angle. The procedures are also designed to apply for any planned landing site. Certain procedures, such as those for anytime LM lift-off from the lunar surface, are very loosely defined. This is due both to the extreme complexity involved and to the lack of confirmed limits (such as the maximim height differential) and ground rules (such as when a combined effort by both vehicles should be utilized).

The procedures were designed to make the vehicles as independent of the MSFN as possible, although the utilization of the maximum possible MSFN back-up capability was a prime consideration. For the vehicles to be independent of the MSFN, it is necessary to use rendezvous sequences for which solutions can be obtained onboard. The two onboard rendezvous sequences are the direct intercept sequence and the coelliptic sequence. The CSM computer contains only the direct intercept sequence, but the LM computer contains both sequences and can compute a coelliptic sequence for a CSM-active rendezvous. Some situations require sequences which are initiated by a maneuver other than an onboard-sequence initial maneuver. These initial "external" maneuvers are designed either to be canned or to use near-standard targeting.

The only major difference between these recommendations and those contained in the previous information (ref. 1) is in the area of aborts from powered descent.

For this note, the lunar orbit phase is divided into three major subphases: (1) Hohmann descent, (2) powered descent, and (3) ascent from the lunar surface.

The procedures are further divided in reference to the active vehicle. For the main body of information, a vehicle is considered either totally active or totally inactive. (A "LM abort" or "LM alone" refers to a totally LM-active rendezvous. A "CSM rescue" refers to a totally CSM-active rendezvous.) Combination rendezvous (maneuvering by both vehicles) is discussed in general in a separate section. However, no specific recommendations are made other than for approximate CSM action when maximum LM-alone action cannot effect rendezvous.

A further division of the procedures categorizes them as either non-time-critical or time-critical. For non-time-critical situations, any abort-to-rendezvous time duration which does not exceed the LM lifetime is acceptable. The maximum time duration from abort to rendezvous normally associated with time-critical situations is about 3 to 4 hours after the time of the associated failure. However, extreme emergencies are assumed to require rendezvous within 1.5 to 2 hours after the failure. Since the time-critical procedures differ for various emergencies, the recommendations for them are not as specific as for the non-time-critical procedures.

The ΔV values presented herein are theoretical and do not reflect operational or manual factors. The ΔV budgets and LM lifetimes used for this study are approximate values based on average situations. Therefore, the corresponding maximum capability information is not exact. However, this information is thought to be not more than 5 to 10 percent in error for any applicable situation. The use of LM-APS fuel through the LM-RCS thrusters is presently not definitely confirmed. Therefore, most of the associated maximum capability data reflect both utilization and nonutilization of this APS fuel capability.

The ΔV budget for CSM rescue is not separated into SPS and RCS allotments, but represents a total SPS/RCS allotment. The separate values are presently not precisely defined. The ΔV budgets and LM lifetimes are:

ΔV budget for in-plane CSM rescue, fps	700
LM RCS rendezvous budget, fps	450
LM RCS rendezvous budget including APS fuel through the RCS system, fps	575
LM unstaged lifetime, hr	55-60
LM ascent stage maximum lifetime[a], hr	12

Likewise, the CSM or LM propulsion system for each maneuver is not specified. The propulsion system used for a certain maneuver is often dependent on the situation. The RCS systems are used only when the larger systems are either nonapplicable or operationally disadvantageous, such as for intercept brakings or, generally, maneuvers less than about 15 fps. However, after ascent from the surface the LM can utilize only RCS thrusting.

Rendezvous Techniques

The three main rendezvous sequences used for the abort and rescue procedures are (1) the direct intercept and (2) the coelliptic sequence, used for both LM aborts and CSM rescues, and (3) the six-impulse technique, used for CSM rescues only. The direct intercept sequence is a two-impulse technique for which the first impulse establishes an intercept trajectory for a selected intercept time, and the second impulse (braking) accomplishes intercept-velocity match.

The coelliptic sequence is a four-impulse technique designed to afford a period of coelliptic coast prior to terminal phase, which is a standardized direct intercept. The coelliptic sequence initiation (CSI) is designed to place the active vehicle on a trajectory from which, at a preselected upcoming apsis, it can become coelliptic with the target vehicle and then obtain a certain preselected relative condition at a preselected time while coasting in the coelliptic orbit. A constant differential height manuever (CDH) is performed to make the orbits of the

[a]The LM ascent stage maximum lifetime of 12 hours corresponds to 9.5 hours from insertion to TPI.

vehicles coelliptic. The preselected relative condition is a line-of-sight elevation angle to the target vehicle utilized to trigger a standardized direct intercept. The terminal phase initiation (TPI) is designed such that the thrust vector is theoretically along the line of sight to the target vehicle. The CSI is constrained to be a horizontal maneuver in order to simplify the logic and, for some cases involving posigrade burns, to avoid lowering pericynthion. The input parameters for a specific sequence are the times of CSI and TPI, the TPI elevation angle, and the number of the apsis after CSI at which CDH is to occur. The variables are the altitude and time of CDH.

The six-impulse technique as defined herein is a rescue technique involving a coelliptic sequence preceded by a Hohmann transfer from the CSM's standard circular parking orbit to a preselected lower circular orbit of approximately 20 n. mi. The coelliptic sequence involved has several unique and advantageous characteristics. CSI, CDH, and TPI all normally occur on the front side of the moon at approximately the same longitude, approximately that of LM pericynthion. For most cases they are one revolution apart; however, a few cases require two revolutions between CSI and CDH. Also, both the coelliptic phase differential height (Δh) and the total ΔV requirements are nearly constant for all applicable cases; Δh ranges from 10 to 12 n. mi. (CSM above), and total ΔV is approximately 300 fps. Reference 2 presents more detailed explanation and data for the six-impulse sequence.

Plane Change Procedures

Most of the procedures and supporting data do not refer to out-of-plane situations. The plane change procedures are essentially common to all the subphases. It is assumed that a wedge angle up to 0.5° would normally be removed by LM powered-ascent yaw steering, and that about 0.2° to 0.3° could be handled during terminal phase. For the coelliptic sequence, CSI and CDH are executed with thrusting parallel to the target vehicle orbital plane. An in-orbit plane change in excess of about 0.3° would require a separate maneuver at a common node of the vehicles' orbital planes. For some cases, such as nominal ascent, a rendezvous delay would probably be required. The active vehicle for a separate plane change would depend on the situation. The LM would be active when a fuel shortage or insufficient time between maneuvers would not result. The CSM has the capability of performing up to approximately a 2° plane change prior to nominal LM lift-off with the objective of providing an in-plane LM powered ascent. For LM anytime lift-offs when this nominal CSM plane change has not occurred, the CSM has at least this 2° plane change capability in addition to its separately allotted rescue budget. The requirement for a large in-orbit plane change is associated with non-nominal postlanding situations. Prior to landing, a large out-of-plane condition would result only for extreme contingencies. The cost of a plane change at a common node is approximately 100 fps per degree of wedge angle. A two-impulse plane change associated with terminal phase could cost anywhere from 100 to 300 fps per degree of wedge angle, depending on the position of the common node.

Nominal Mission Summary

The LM is assumed to be essentially in the nominal trajectory at the time of abort or rescue. The nominal descent is described in the Hohmann descent and powered descent sections of the text. To provide a quick reference, a brief summary of the current nominal ascent profile is presented here. A coelliptic sequence incorporating Δh's between 15 and 50 n. mi. with the LM below is utilized. The "on-time" earliest nominal lift-off results in a Δh of 15 n. mi., and the latest nominal lift-off (about 4.5 minutes later) results in a Δh of 50 n. mi. There is currently consideration being given to decreasing this maximum nominal Δh. For all nominal lift-offs, the LM inserts into the standard 30- by 10-n. mi. ascent orbit. CSI is executed approximately 30 minutes after insertion and is based on TPI occurring approximately 80 minutes after CSI, that is, when the CSM is essentially back over the landing site. CDH is executed at the predicted time of the first apocynthion following CSI at an elapsed time from CSI of between 50 minutes (Δh = 15 n. mi.) and 26 minutes (Δh = 50 n. mi.). The angle through which the target vehicle travels during terminal phase (ϕ) is 140° and the TPI elevation angle is approximately 27°. As Δh ranges from 15 to 50 n. mi., the ΔV's for the in-orbit RCS maneuvers range as follows: CSI = 60 to 0 fps, CDH = 66 to 31 fps, TPI = 25 to 82 fps, braking = 26 to 83 fps; the total ΔV is 177 to 196 fps. TPI is nominally positioned to obtain the most favorable lighting conditions; this factor is also implemented in the abort procedures where possible. The times of CSI and TPI (and CDH for a given Δh) relative to LM lift-off vary only slightly for the different possible landing sites.

SYMBOLS

APS	ascent propulsion system
CDH	constant differential height (coelliptic) maneuver
CSI	coelliptic sequence initiation
CSM	command and service modules
DPS	descent propulsion system

HDM	Hohmann descent maneuver
LM	lunar module
RCS	reaction control system
SPS	service propulsion system
TE_H	elapsed time from Hohmann descent initiation, min
TE_i	elapsed time from LM insertion, min
TE_P	elapsed time from powered descent initiation, min
TPI	terminal phase initiation
Δh	coelliptic differential altitude, n. mi.
$\Delta\theta$	CSM lead angle, deg
$\Delta\theta_i$	CSM lead angle at LM insertion, deg
ϕ	target vehicle travel angle during terminal phase, deg

HOHMANN DESCENT

The Hohmann descent is the half-revolution coasting descent of the LM nominally from the 80-n. mi. circular altitude of CSM to the 8.23-n. mi. or 50 000-ft altitude for powered-descent initiation. The Hohmann descent is nominally initiated by a 100-fps horizontal retrograde DPS burn when the LM is essentially in the 80-n. mi. circular orbit. A phase-angle (CSM lead angle, $\Delta\theta$) profile referenced to the elapsed time from Hohmann descent initiation (TE_H) is shown in figure 1.

The LM aborts and CSM rescues for this subphase involve all of those which are initiated when the LM is in the Hohmann descent orbit, including those initiated after the powered-descent initiation time when powered descent was not initiated.

Assuming full electrical power capability from both stages, it is emphasized that the unstaged LM lifetime is between 55 and 60 hours.

LM Aborts During Hohmann Descent

For in-orbit aborts, the LM initiates a return to the CSM, which is in the 80-n. mi. circular orbit. The abort maneuver itself is a rendezvous maneuver, either a CSI or a direct intercept initiation, not just a circularization or a burn utilizing a standard target. Staging does not occur prior to the abort maneuver unless the descent engine is rendered unusable. It has not been determined when to stage a usable descent stage prior to rendezvous, if it is necessary.

Non-time-critical LM aborts.- Three abort procedures are recommended, the applicable procedure depending on TE_H. If the abort decision is made sufficiently early to allow execution of the initial abort maneuver at $TE_H \sim 10$ minutes, a direct intercept ($\phi = 140°$) is initiated at that time. The resulting terminal approach is equivalent to a nominal coelliptic sequence approach for Δh of approximately 10 n. mi. For aborts with the initial abort maneuver at TE_H's between approximately 10 and 20 minutes, a coelliptic sequence with CSI as the initial abort maneuver and TPI approximately 1.5 revolutions (3 hours) after the Hohmann descent initiation (HDM) is recommended. For aborts initiated after $TE_H \sim 20$ minutes, the same type sequence is utilized, but with TPI occurring approximately 2.5 revolutions (5 hours) after HDM instead of 1.5 revolutions. For all of these Hohmann descent coelliptic sequence aborts, CDH occurs at the first apocynthion following CSI, and the LM is about 10 to 20 n. mi. above the CSM. The purpose of the delay in TPI for aborts initiated after $TE_H \sim 20$ minutes is to maintain Δh within the 10- to 20-n. mi. range. Premission selected initial abort maneuver times, although not specifically recommended for this mode after $TE_H = 10$ minutes, could be utilized.

Figure 2 presents a summary of the recommended procedures and the ΔV and Δh values. Figure 3 presents general data which were utilized as a basis for determination of the recommended procedures.

Time-critical LM aborts.- For an abort initiated at TE_H less than approximately 30 minutes, a direct intercept with $\phi \sim 140°$ is operationally feasible although the ΔV requirements increase considerably after $TE_H \sim 20$ minutes. After $TE_H \sim 30$ minutes, direct intercepts with $\phi < 180°$ result in both unsafe pericynthions and excessively high braking ΔV requirements. In order to maintain clear pericynthions and acceptable

ΔV requirements, direct intercepts with $\phi \sim 270^\circ$ are recommended when the initial abort maneuver occurs after $TE_H \sim 30$ minutes. For TE_H's between 50 and 70 minutes, the pericynthion altitudes for these $\phi = 270^\circ$ direct intercepts are only slightly above the clear pericynthion limit of 35 000 ft. For questionable (dispersions) cases in this TE_H range, it is recommended that either a colliptic sequence with TPI at the earliest operationally feasible opportunity or an intermediate phasing trajectory of 30 to 60 minutes be utilized. For aborts initiated after $TE_H \sim 30$ minutes, coelliptic sequence rendezvous with Δh in the 30- to 60-n. mi. range (LM above) require only about 1 to 1.5 hours longer than direct intercepts or three-impulse rendezvous, which are considerably less desirable operationally. Data pertaining to such coelliptic rendezvous are contained in figure 3. Direct intercept rendezvous data showing total ΔV as a function of ϕ, with curves for abort initiation at various TE_H's (for the clear pericynthion cases) are presented in figure 4.

CSM Rescues During Hohmann Descent

For CSM rescue during this phase of the lunar mission, the CSM must initiate a rescue sequence which achieves the LM Hohmann descent orbit while maintaining a safe pericynthion altitude. The initial maneuver may be a direct intercept or external maneuver, depending on what time during the Hohmann descent the CSM is required to initiate rescue. It should be pointed out that the initial rescue maneuver could never be a CSI if a safe pericynthion altitude is to be maintained because the four-impulse coelliptic sequence would force the CSM to go into a coelliptic orbit below the LM whose pericynthion altitude is 50 000 ft.

Non-time-critical CSM rescues.- As in the case for LM aborts during the Hohmann descent, three CSM rescue procedures are recommended as a function of TE_H. If the rescue decision is made sufficiently early such that the CSM is prepared to maneuver prior to $TE_H \sim 10$ minutes, a direct intercept maneuver ($\phi = 140^\circ$) is initiated at $TE_H \sim 10$ minutes. This procedure is similar to a LM abort during this time. Rendezvous will occur about 57 minutes from HDM with a total fuel expenditure of about 145 fps, of which approximately 8 fps is required for braking. The transfer orbit pericynthion will be about 50 000 ft (8.2 n. mi.). The rescue procedure is initiated while both vehicles are behind the moon and out of communication with the MSFN; therefore, since no ground assistance is available to the CSM, the CSM must rely on either its own onboard system or that of the LM.

In the event the CSM is made aware of a rescue situation and is prepared to maneuver prior to $TE_H \sim 20$ minutes, a direct intercept maneuver ($\phi = 120^\circ$) is initiated at $TE_H \sim 20$ minutes. A transfer angle of 140° at this time of initiation results in a pericynthion below 40 000 ft, while a 120° transfer angle will permit a pericynthion altitude of about 50 000 ft. Rendezvous will occur about 60 minutes from HDM with a total fuel expenditure of about 310 fps, of which about 50 fps is required for braking. For rescue initiation during this time period, just as for rescue at $TE_H \sim 10$ minutes, no ground assistance is available.

For rescue situations arising after $TE_H \sim 20$ minutes, and prior to the time of LM powered-descent initiation, the six-impulse technique will be utilized. The initial rescue maneuver occurs at the time the CSM crosses the longitude of LM pericynthion, and the circularization maneuver (nominally at 20 n. mi.) occurs 180° from the initial maneuver.

Approximately over the longitude of upcoming LM pericynthion, the CSM will perform the CSI maneuver. CDH occurs one revolution after CSI, and TPI, two revolutions after CSI. By having the CSI maneuver over LM pericynthion, a Δh of approximately 12 n. mi. above the LM orbit is achieved. Rendezvous will occur approximately 7.75 hours from HDM with about a 300-fps fuel requirement. The braking maneuver will be about 18 fps. It is advisable to delay the initial rescue maneuver until the CSM arrives at LM pericynthion as this procedure allows MSFN assistance.

The possibility also exists that a rescue situation may not be realized until after the time of LM powered-descent initiation, for which the LM does not initiate powered descent. In this event, the CSM will initiate the six-impulse sequence as soon after the rescue command as it is able to prepare for the maneuver.

If the initial maneuver is performed prior to approximately 75 minutes after HDM, the six-impulse sequence will be executed as previously discussed. However, if the initial maneuver is not performed prior to $TE_H \sim 75$ minutes, the CDH and TPI maneuvers will each be delayed one revolution, though they occur over the same longitude. This extra 2-hour rendezvous requirement is brought about by the fact that after $TE_H \sim 75$ minutes, the CSI maneuver will be retrograde. Since the CSM is in a 20-n. mi. circular orbit prior to CSI, a retrograde CSI should be avoided.

The MSFN would probably send the CSM the first two maneuvers of the six-impulse sequence on the last earth-side pass prior to LM separation and HDM. It should be pointed out that only two maneuvers, circularization at 20 n. mi. and braking, would occur behind the moon. The CSM would have both the ground and LM onboard solutions available for the CSI, CDH, and TPI maneuvers.

Figure 5 summarizes the non-time-critical CSM rescue procedures for the Hohmann descent phase. Total ΔV, CSI ΔV, and Δh data are included.

Time-critical CSM rescues.- As in the case for a non-time-critical CSM rescue, there are three procedures for time-critical CSM rescue as a function of TE_H. In fact, the two procedures for non-time-critical CSM rescues for TE_H up to 20 minutes also apply to time-critical situations.

The procedure to be followed for time-critical rescue after $TE_H \sim 20$ minutes is still under study. Figure 6 illustrates the direct-intercept capabilities as a function of ϕ; curves for abort initiations at various TE_H's (for the clear pericynthion cases) are shown. As shown in this figure, the direct-intercept capabilities are greatly reduced by delaying the initiation of the first maneuver. Not only do the braking and total fuel requirements greatly increase but the transfer angles that will yield a safe pericynthion for the transfer orbit become limited. It is obvious from figure 6 that should a time-critical situation arise about the time the LM would nominally start powered descent (60 minutes), use of the direct intercept is virtually eliminated.

As pointed out before, an answer to this time-critical, late-realized rescue situation has not as yet been reached. It is being comtemplated that the CSM should do one or more phasing maneuvers and then proceed to the direct intercept. It should be mentioned, however, that unless the large braking maneuvers resulting from a direct-intercept sequence are accepted, a time savings of more than about 2.5 hours over that of the six-impulse technique is unlikely.

POWERED DESCENT

Powered descent is nominally initiated at pericynthion of the Hohmann descent orbit at $TE_H \sim 58$ minutes, and touchdown on the lunar surface occurs at an elapsed time from powered descent initiation (TE_P) of approximately 12 minutes. It is assumed that an abort could be initiated at any TE_P to within about 30 seconds of touchdown. For any powered descent abort after DPS full thrust has occurred, the LM should insert back into an 80- by 10-n. mi. orbit, which is the target orbit in the insertion routine prior to landing. This orbit affords both LM-active rendezvous and CSM rescue throughout the powered-descent abort region. For considerably lower insertion orbits (e.g., the standard ascent orbit) the CSM cannot establish phasing below the LM sufficient to afford rescue for early abort situations. For aborts prior to full thrust (TE_p < 26 seconds), the only action should be to shut down the DPS. The insertion routine, which would involve extreme attitude and maneuver logic complexities, need not be called, since the resulting LM orbit prior to full thrust is approximately 60- by 8-n. mi. The exact reinsertion time corresponding to a particular abort time is dependent on whether staging occurs and certain other factors. However, these exact reinsertion times do not vary significantly from an average curve used to generate the associated data herein. As seen in figure 7, the range for the CSM lead angle at LM insertion ($\Delta\Theta_i$) for aborts from powered descent is approximately -10° to +20°: Range and elevation angle data applicable to this subphase are presented in figure 16.

Maximum ground support and vehicle-to-vehicle contact are available for initial activities associated with these aborts.

LM Aborts During Powered Descent

Following an abort during powered descent, the initial in-orbit maneuver occurs between approximately 10 and 30 minutes after insertion, depending on the time criticality. For early powered-descent aborts when LM staging does not occur prior to insertion, the DPS could be utilized for the initial in-orbit burns.

Non-time-critical LM aborts.- For all non-time-critical situations following aborts during powered descent, the LM initiates a coelliptic sequence approximately 30 minutes after insertion back into orbit. TPI occurs approximately two revolutions after insertion. The two revolutions to TPI not only afford a slower timeline with a "CSI recycle" opportunity, but also maintain Δh within a desirable range. For aborts at TE_p's between 0 and approximately 6 minutes, CDH occurs at first apocynthion. For aborts after $TE_p \sim 6$ minutes, CDH occurs at second apocynthion. This latter sequence theoretically avoids both a retrograde CSI and $\Delta h = 0$.

A summary of these procedures, showing Δh, CSI ΔV, and total ΔV, is presented in figure 8. Figure 9 contains corresponding general coelliptic data.

Time-critical LM aborts.- Coelliptic sequences with CSI about 30 minutes from insertion and TPI approximately one revolution after insertion apply for aborts at any time during powered descent. The corresponding Δh's are from about 60 n. mi. (LM above) for aborts at the beginning of powered descent to 25 n. mi. (LM below) for aborts from hover, although retrograde CSI's would be required for hover aborts. For an abort resulting in a Δh near 0 (for CSI at TE_i = 30 minutes), a delay in CSI of about 15 minutes or a direct intercept should be incorporated.

In fact, for aborts at TE_P's between approximately 7 and 11 minutes (end of hover), direct intercepts for ϕ less than 180° initiated between 10 and 30 minutes after insertion are operationally feasible. The applicable parameters are shown by figure 10. The $\Delta\Theta_i$ range which applies is approximately 5° to 20° (end of hover equivalent).

For situations when immediate direct intercepts are not feasible and coelliptic sequences are too slow, intermediate LM phasing trajectories or CSM assists must be utilized.

CSM Rescues After Powered-Descent Aborts

For CSM rescue during this subphase, the CSM must maintain a safe pericynthion altitude and initiate a rescue sequence which achieves the LM 80- by 10-n. mi. orbit after the LM aborts from powered descent. The rescue sequence must also allow rendezvous and crew transfer within an absolute maximum of about 12 hours from LM insertion when the LM ascent stage only is involved.

The initial rescue maneuver may either be a rendezvous maneuver or an external maneuver, depending upon the phasing conditions at LM insertion. Maximum opportunity for ground assistance exists.

Non-time-critical CSM rescues.- The procedure to be followed for non-time-critical CSM rescue after the LM aborts from powered descent is a function of the relative phasing conditions achieved at LM insertion, which under normal conditions may be related to the time during the powered descent that the LM aborts (see fig. 7).

Two basic maneuver sequences are recommended for rescue during this phase of the lunar mission: the normal four-impulse coelliptic sequence and the six-impulse sequence, the proper technique being governed by insertion conditions. Whichever technique is required, it is assumed that the initial maneuver would not be made until about 30 minutes from LM insertion, as this would likely be the earliest time a need for rescue would be discovered.

If the LM should insert with a $\Delta\Theta_i$ of less than about 8°, then a six-impulse sequence will be required. This 8° corresponds to a LM abort of earlier than about 8 minutes into powered descent. If the LM inserts with a $\Delta\Theta_i$ of greater than 8°, the four-impulse coelliptic sequence will be used. The ground should be in contact with the vehicles at LM insertion and should be able to advise the CSM of the technique required.

In the event a six-impulse technique is required for a possible rescue, the ground would send the CSM the first two maneuvers of the six-impulse sequence. If a rescue is actually needed, the CSM executes these first two maneuvers to circularize at 20 n. mi. The CSI maneuver will occur over the longitude of LM pericynthion; CDH, one revolution after CSI; and TPI, one revolution after CDH. The CSM will then be able to receive both the LM solution and the ground solution for CSI before having to perform the CSI maneuver. If the CSI maneuver should be retrograde, which will normally be the case if the LM aborts earlier than about 3 minutes into powered descent ($\Delta\Theta_i \sim -6^\circ$), CDH will then be placed two revolutions after CSI, and TPI, one revolution after CDH. The Δh will be 10 n. mi. (CSM above), and the total fuel requirement will be about 300 fps. The time of rendezvous will be between 7.75 hours and 9.75 hours, depending on whether CDH is one or two revolutions after CSI.

In the event a four-impulse coelliptic sequence is utilized, the ground will probably have to provide the CSM with the CSI maneuver, as the LM will be computing the CSI maneuver based on its being the active vehicle. The ground will compute CSI based on CDH occurring at the upcoming pericynthion with TPI occurring about one revolution from LM insertion. In the event Δh increases to above 20 n. mi. (CSM above LM), TPI will be delayed one revolution. This TPI delay nominally occurs when $\Delta\Theta_i$ exceeds approximately 13°. The rendezvous time will be between 2.75 and 4.75 hours from LM insertion, depending on whether TPI is one or two revolutions from insertion.

For all non-time-critical rescue procedures during this phase of the lunar mission, the terminal phase maneuvers are initiated from coelliptic orbits. The Δh's range from about 10 and 20 n. mi. with the CSM above the LM.

Figure 12 summarizes the non-time-critical CSM-rescue procedures for powered-descent aborts. Figure 13 presents corresponding general six-impulse data, and figure 14 presents corresponding general coelliptic sequence data. Each of these figures shows Δh, total ΔV, and CSI ΔV as functions of $\Delta\Theta_i$.

Time-critical CSM rescues.- As in the case of a time-critical CSM rescue during Hohmann descent, no definite procedures are available at this time and work is continuing in this area.

Figure 15 illustrates the capabilities of utilizing the direct intercept in order to effect rescue based on initiating the intercept maneuver 10 minutes after LM insertion into an 80- by 10-n. mi. orbit. This technique is virtually eliminated for early aborts due to the excessively high braking and total fuel requirements. For early aborts, a delay in initiation of the intercept maneuver will result in a worse situation. For late aborts, it would be advantageous to wait until prior to rescue initiation to initiate the intercept maneuver. Even for late aborts (as late as hover), the required performance from the CSI is greatly dependent on the transfer angle from initiation to rendezvous. It may be operationally unfeasible to select the proper transfer angle in real time unless mission rules will allow very large CSM braking maneuvers. The minimum braking is about 100 fps.

For late aborts the coelliptic sequence for the region where TPI is one revolution from LM insertion could be considered as a time-critical procedure. However, for $\Delta\Theta_i$'s consistent with aborts from hover, Δh is in the 40- to 50-n. mi. range with the CSM above.

ASCENT FROM SURFACE

All information presented for this subphase is based on a nominal powered-ascent trajectory. The insertion target for the 30- by 10-n. mi. orbit is input subsequent th LM landing, since during the descent phase an 80- by 10-n. mi. insertion orbit is in the insertion routine. The modes and procedures for this subphase are determined by various LM situations (involving life support, fuel, maneuverability, power, etc.) either before, during, or after powered ascent in conjunction with LM lift-off.

The subphase is divided into three general categories based on LM lift-off time: (1) nominal launch window lift-offs, (2) in-orbit direct intercept lift-offs, and (3) anytime lift-offs. A nominal launch window lift-off is one designed to yield a Δh between the nominal coelliptic sequence Δh limits, which are presently 15 to 50 n. mi. with the LM below. For the current nominal ascent plan, the corresponding range for CSM lead angle at LM insertion ($\Delta\Theta_i$) is approximately 20° to 33°, which is equivalent to a nominal launch window time duration of about 4.5 minutes.

An in-orbit direct intercept lift-off initiates a technique in which a direct intercept ($\phi \sim 100°$ to 140°) by either vehicle is initiated as soon as is operationally feasible, 10 to 15 minutes after LM insertion into orbit. When the LM insertion targeting has not been switched to the standard orbit conditions, or when there is sufficient time to switch back to the 80- by 10-n. mi. orbit insertion conditions, the LM inserts into the 80- by 10-n. mi. orbit. Otherwise, the standard orbit is utilized. The larger orbit is advantageous to both LM-active and CSM-active rendezvous for this situation. This technique is obviously a time-critical procedure and is not considered for non-time-critical situations.

An anytime lift-off is one neither within the nominal launch window nor at a selected in-orbit direct intercept lift-off time. This type lift-off is utilized only when it is determined that the LM could not obtain orbit by waiting for a nominal lift-off or an in-orbit direct intercept lift-off. In other words, an anytime lift-off occurs as soon as possible after the emergency situation is realized. Situations requiring an anytime lift-off are a major fuel system leak or a lunar environment contingency such as a solar flare or moon quake.

The concensus of opinion is that the probability of an anytime lift-off is relatively small. However, the development of detailed procedures to cover the entire anytime lift-off window, i.e., all $\Delta\Theta_i$'s other than those of the nominal launch window, is necessary. These exact procedures are presently not sufficiently defined to merit inclusion in this note. The included data for this subphase (fig. 17) involve only maximum capability curves which show the $\Delta\Theta_i$ ranges corresponding to the maximum ΔV capabilities and certain constrained parameters such as Δh, TE_i for CSI, or total ascent time. For any one $\Delta\Theta_i$ within about 60 to 70 percent of the total 360°, numerous solutions result by varying parameters such as time of CSI, time of TPI, or the apsis for CDH. In some cases, several of these solutions differ only slightly, complicating the choice of solution. It is highly improbable that a very small $\Delta\Theta_i$ (between $\pm 15°$) would result from an anytime lift-off, since a lift-off delay of 10 minutes or less would eliminate such a $\Delta\Theta_i$.

Reference 3 indicates a small fraction of the complexity of the anytime lift-off situation; it involves CSM rescue using coelliptic sequence rendezvous in which only two parameters, time of TPI and apsis of CDH, are varied.

Basically, the anytime lift-off procedures are dependent on presently unanswered questions such as, "What are the LM's maximum operational capabilities (Δh, ΔV, total ascent time) above which a CSM assist is required?" and "Where possible, will extra logic and maneuvers be utilized to establish rendezvous from below when rendezvous from above would be faster and more direct?"

LM Aborts During Ascent

The reasons for an abort after a nominal lift-off are summarized as follows: (a) large initial dispersions, especially out-of-plane dispersions, (b) lack of necessary information sufficiently prior to CSI, (c) a large execution error in CSI, or (d) the realization of a time-critical situation. In general, the ascents following most of these aborts can be designed to afford nominal terminal conditions and in-plane ΔV requirements which do not excessively exceed those of the nominal, but usually require an additional revolution.

For in-orbit direct intercept lift-offs it is emphasized that the abort technique is a time-critical procedure designed prior to LM lift-off.

For anytime lift-offs, the CSM does not assist within a separate set of defined limits (see "Non-time-critical LM aborts" and "Time-critical LM aborts") for each non-time-critical and time-critical situation. However, for the current operational maximums of LM-RCS ascent ΔV and LM lifetime, there are no possible LM-alone coelliptic sequence solutions for a $\Delta\Theta_i$ gap of approximately 60° (fig. 17). This gap is theoretically closed by LM-alone action if either use of the APS fuel in excess of that required for nominal powered ascent (about 125 fps through RCS thrusters) or use of a 50 000-ft circular LM orbit from insertion is assumed. Each degree of plane change made by the LM reduces the maximum capability by about 50° for the LM above the CSM region.

Anytime lift-off LM abort procedures can be generally summarized as follows. For $\Delta\Theta_i$'s between approximately 10° to 180°, the LM remains below the CSM. The larger the $\Delta\Theta_i$, the longer the time normally spent in the minimum or near-minimum orbit. For $\Delta\Theta_i$'s from approximately 10° back to -180°, the LM maneuvers above the CSM to establish negative catchup. The larger the $\Delta\theta_i$, the higher the LM phasing orbit and/or the longer the time spent in the orbit. For the previously noted $\Delta\theta_i$ gap requiring CSM assists, a LM orbit at least as high as the nominal CSM parking orbit is highly advantageous.

A plot of minimum total ΔV and terminal phase ΔV for coelliptic ascent as a function of Δh is presented in figure 19.

Non-Time-Critical LM Aborts During Ascent.-

Nominal launch window lift-off: The abort procedures are dependent on the reason for the abort (see p. 17). For initial dispersions, TPI would be delayed one revolution to allow sufficient time for a separate plane change, made by the LM or the CSM. For insufficient information prior to CSI, either CSI would be delayed 10 to 15 minutes or a canned CSI maneuver would be applied at the nominal time; in either case, TPI might be delayed a revolution, depending on the situation following CSI. For a large CSI execution error, either the times and Δh's for CDH and TPI would be adjusted or a second CSI would be scheduled between 30 to 120 minutes after the nominal CSI. TPI would be delayed one revolution.

Anytime lift-off: When afforded a choice (i.e., for $\Delta\theta_i$'s less than approximately $\pm 120°$), an ascent sequence which maintains a relatively small Δh in exchange for increased total ascent time will probably be selected. For example, for an anytime lift-off resulting in a $\Delta\theta_i$ of approximately 65°, either a two-revolution ascent with Δh between 40 and 50 n. mi. or a three-revolution ascent with Δh between 10 and 20 n. mi. could be utilized. Similar situations exist for $\Delta\theta_i$'s for which the LM maneuvers above the CSM. Favorable terminal lighting conditions are also considered. As previously discussed, no attempt is made to define the exact procedures for all ranges of $\Delta\theta_i$, but only boundary curves are considered. For non-time-critical situations, it is assumed realistic to use up to about 95 percent of the LM lifetime, which is about 9.5 hours between LM insertion and TPI. Using the operational LM lifetime and ΔV maximums the $\Delta\theta_i$ ranges for various Δh's and times of CSI are shown in figure 17, which is a plot of $\Delta\theta_i$ as a function of the number of revolutions from LM insertion to TPI. (Each revolution is equivalent to approximately 2 hours.) Approximate interpolations can be made between different Δh boundaries to estimate trade-offs in Δh and Δt.

Time-Critical LM Aborts.-

Nominal launch window lift-off: It is assumed that the time-critical situation does not exist prior to lift-off. Due to the required LM coast for phasing in the standard ascent orbit, the total ascent time is not substantially decreased by using an operationally feasible direct intercept instead of the nominal coelliptic sequence. For the quickest situation (earliest nominal lift-off, $\Delta\Theta_i \sim 20°$), the direct intercept affords a savings of only 30 to 45 minutes. Therefore, except for extreme emergencies, the nominal ascent sequence should be used even for time-critical situations of this type.

In-orbit direct intercept lift-off: This procedure is designed specifically for a time-critical situation realized prior to lift-off. The technique, which would be labeled as a "semi-direct ascent," has been basically described. Total ΔV and braking ΔV (associated with pericynthions above approximately 5 n. mi.) as a function of ϕ are shown in figure 10 with curves for various $\Delta\Theta_i$. The LM insertion orbit is 80- by 10-n. mi., and the delays between LM insertion and direct intercept initiation are 10 and 30 minutes.

The same type information is shown in figure 11 for a LM insertion orbit of 30- by 10-n. mi. The favorable ϕ range is between approximately 100° and 140°; these ϕ's are large enough to avoid extremely high braking and far enough below 180° to avoid major problems in handling out-of-plane situations. A plane change larger than that feasible for the LM to make using the direct intercept would be made by a separate CSM maneuver at a common node of the two vehicles' orbits.

Anytime lift-off: Except for a limited range of $\Delta\Theta_i$'s within about $\pm 30°$ of the nominal launch window, there is actually no "LM-alone" time-critical, anytime lift-off. (For larger $\Delta\Theta_i$'s, CSM assists would most probably be utilized.) For this limited "LM-alone" range, the LM will use the sequence which affords the most operationally desirable rendezvous within the time limit; the sequence may be a two-, three-, or four-impulse sequence. The use of critical parameters and near-maximum ΔV capability is probable. No data is specifically presented for this mode; however, various data presented for other modes, such as those for the in-orbit direct intercept lift-off and anytime lift-off, as in figure 17, are applicable to this mode.

CSM Rescue During Ascent

For the three categories of LM ascent, the possibility exists that the CSM may be required either to perform a totally CSM-active rendezvous or to lend assistance to the LM. This condition can be brought about for one of three reasons:

(1) The LM is completely nonpropulsive after insertion.

(2) The LM performs the CSI maneuver and then becomes nonpropulsive.

(3) The LM insertion conditions were such that, using the maximum LM lifetime, the fuel requirement for LM-active rendezvous is outside the LM capability.

Based on the standard LM insertion orbit, a gap exists in the LM launch window where CSM rescue is not possible within the LM lifetime. This gap is bounded by a LM launch which is about 20 minutes earlier than the start of the nominal launch window and extends to a LM launch which is about 3 minutes earlier than the start of the nominal launch window. This boundary is based on using the maximum CSM-rescue fuel capability, deleting the coelliptic coast phase, using the maximum LM system lifetime, and accepting differential altitudes at TPI of between 50 and 70 n. mi. (over 100 fps braking velocity). Using the above maximums but including a coelliptic orbit phase will cause the gap to widen about 5 minutes. The boundary conditions for CSM rescue are shown in figure 20.

<u>Non-time-critical CSM rescue</u>.-

Nominal launch window lift-off: Excluding any excessive plane change, the capability exists for a CSM rescue for a LM lift-off during the nominal launch window.

In the event the LM becomes nonpropulsive immediately after insertion (or prior to the LM-active CSI maneuver), the CSM should initiate the coelliptic sequence 30 minutes after insertion with CDH occurring at the upcoming apsis after CSI and TPI ($\phi = 140^\circ$) occurring over the landing site on the next pass. If the differential altitude is larger than the mission constraints allow, it may be controlled by slipping TPI by one or more revolutions. It should not require more than about three revolutions between insertion and TPI to maintain a differential altitude of 15 n. mi. above the LM orbit for nominal launch window lift-offs.

Since the LM would be computing the CSI maneuver based on its being the active vehicle, the ground would probably have to send the CSM the CSI maneuver and CDH time. A CDH update would then be computed for the CSM by the LM.

It should be noted that the CSM cannot coast more than approximately 50 minutes prior to execution of the CSI maneuver. Since the LM will be catching up to the CSM at a rate of about 38° per revolution, the resultant phasing would not allow CSM rescue.

In the event the LM is able to perform CSI and then becomes nonpropulsive, the CSM will perform the coelliptic maneuver at the time the LM had planned to perform it. The LM will compute the CDH maneuver for the CSM. The differential altitude should nominally be about the same as that computed prior to CSI, assuming the LM is active. The CSM will then have the option to coast either to the planned time of TPI or to the time of the nominal elevation angle occurrence before initiating the TPI maneuver ($\phi = 140°$).

Anytime lift-off: Should the LM lift off at anytime during the planned stay on the lunar surface, insert into the standard orbit, and then become nonpropulsive, a CSM rescue is required but may not be possible. If LM insertion occurs in the no-rescue gap and the LM indeed cannot maneuver, then, unless an added amount of fuel or LM lifetime can be obtained, rescue cannot be achieved. However, since the CSM nominal plane change is unlikely to have been performed prior to LM lift-off approximately 200 to 300 fps additional fuel may be available. This additional fuel would close the no-rescue gap, provided a plane change is not required. However, if a plane change is required that consumes more than the plane change allotment, the gap is made wider.

For other insertion phasings, many possible procedures exist for the CSM to follow in effecting a rescue. For example, the CSM could use its maximum rescue budget fuel capability in achieving a 260- by 80-n. mi. orbit shortly after LM insertion. It then could coast for some number of revolutions and, at pericynthion, either initiate a TPI maneuver or perform a coelliptic maneuver followed by TPI about 30 minutes later. For other insertion conditions, a normal coelliptic sequence is sufficient provided the proper set of inputs is used. It should be pointed out that for certain phase angles at insertion, the CSM could not possibly take any rescue action immediately as it would not have communication with either the ground or LM and, hence, would not be aware of the situation. In that event, the CSM would coast until it could be informed of the contingency. A great deal of work needs to be done in order to recommend rescue procedures for an anytime LM lift-off. As pointed out before, there are situations for which many different possible procedures overlap, while there are other situations for which critical parameters are the only choice.

Time-critical CSM rescue.-

Nominal launch window lift-off: For time-critical CSM rescue after the LM has lifted off during the nominal launch window, it is assumed that the need for rescue does not occur until after the LM inserted into the standard orbit. At that time, the LM experiences some failure in addition to a propulsion failure which makes it necessary for rescue to occur as quickly as possible. It is again emphasized that the parameters which are generally constrained for non-time-critical rendezvous are relaxed in exchange for an earlier rendezvous time.

For a LM contingency after insertion, the CSM will have to coast for approximately 20 to 30 minutes after LM insertion to obtain the LM vector and prepare for the maneuver.

If the LM lifts off early in the launch window, a direct intercept may be performed at that time. However, the transfer angle will have to be larger than about 220° to maintain a safe pericynthion. This results in a rendezvous time greater than 1.5 hours from insertion and saves only about 1 hour in comparison with the coelliptic sequence, but results in higher braking maneuvers and unfamiliar approaches in most cases.

As the LM lifts off later in the launch window, the transfer angle to maintain a safe pericynthion is reduced to less than 160°. However, to avoid excessive fuel consumption, the CSM is required to coast much longer prior to initiating the initial intercept maneuver so that there is little, if any, time savings in comparison with the coelliptic sequence.

In-orbit direct intercept lift-off: For CSM rescue for this situation, it is assumed the LM had knowledge of a rescue situation prior to lifting off the lunar surface. In this event, the LM chose to lift off at such a time that the CSM could initiate a direct intercept maneuver shortly after LM insertion into orbit. The CSM would also be aware of the situation prior to LM insertion. The LM lift-off time would probably be about 3 minutes earlier than the start of the nominal launch window. The CSM could then perform a 140° transfer maneuver about 10 minutes after LM insertion and still effect a rendezvous maintaining a safe pericynthion and staying within the fuel requirements. Of course, the plane change probably would not have been made, so, as discussed previously under non-time-critical CSM rescue procedures for an anytime lift-off, plane-change considerations would also have an effect on required CSM performance. Rendezvous would occur about 1 hour from LM insertion.

Anytime lift-off: In order to achieve a time-critical CSM rescue within one revolution for an anytime LM lift-off, the LM must lift off between the earliest time for an in-orbit, direct intercept and the start of the nominal launch window. For other lift-off times, the CSM will have to utilize coasting periods or phasing maneuvers prior to initiation of the direct intercept in order to achieve TPI conditions that will be within the fuel capability of the CSM and also maintain a safe pericynthion. It is emphasized that a time-critical situation may require several orbits to achieve, depending on when the LM lifts off. Then, too, there is the possibility that the LM may insert into the no-rescue zone, for which no procedure can be recommended at this time.

COMBINED VEHICULAR ACTIVITY

The information in the foregoing sections is based on the assumption that either the LM is totally active within its maximum capability or it is totally inactive during CSM rescue. However, there is a possibility that the abort procedures will involve CSM assist earlier than indicated in order to afford a more operationally desirable terminal phase or an earlier rendezvous. It is also possible that prior to predicted inactivity the LM will be able to improve a CSM-rescue situation.

Since this "combined mode" has been only superficially investigated at present, no specific recommendations are included. However, a discussion of various considerations and potentialities is included.

Certain ground rules must be defined before designing detailed procedures in this area. A probable, general ground rule is that the LM should maintain the capability to perform terminal phase. Other ground rules should be defined to specify the total ascent time and the Δh beyond which the CSM assist should be used. It should also be decided whether (when feasible) to set up an active-vehicle terminal approach from below at the cost of time and fuel and usually additional maneuvers.

The anytime lift-off area is the main area for consideration of combined vehicular activity. Except for extremely time-critical situations, rendezvous associated with the other modes and subphases can be accomplished well within the maximum capabilities without combined activity; however, for certain of these less critical situations, should rendezvous from below and relatively small Δh's be required, combined activity would be utilized.

A typical CSM-assist procedure involves a CSM dwell (phasing) orbit to either increase or decrease its orbital period for a selected number of revolutions. Based on ΔV budget the maximum dwell orbit of this type is approximately 260 by 80 n. mi.; the minimum dwell orbit is about 80 by 10 n. mi. based on safety considerations. The maximum assist capabilities reflecting these values are presented in figure 18.

For another type of CSM assist, the CSM might transfer to a different circular orbit, or it might set up a LM-active terminal phase by performing various phasing maneuvers.

A "LM-assist" situation could result in connection with an anytime lift-off caused by a fuel leak. In such a situation (i.e., the LM could become nonpropulsive soon after insertion), the LM orbit would probably be substantially increased soon after insertion if deemed advantageous to CSM rescue. Figure 20 shows the maximum capability for a CSM-rescue situation when the LM is in an 80- by 10-n. mi. orbit.

Studies designed to thoroughly investigate this extremely large and complex area are presently being initiated.

CONCLUDING REMARKS

The information in this note, though preliminary, should serve as a basis for initial associated analyses and planning. The areas with vaguely defined procedures are currently under detailed investigation, and more specifically defined procedures are forthcoming.

It is emphasized that many of these forthcoming procedures are dependent on presently undefined ground rules involving decision logic and limiting parameters for combined vehicular activity.

The most critical situations for LM-alone activity result from anytime lift-offs with large negative phasings (CSM trailing). CSM assists are probable for these situations.

Assuming a totally nonpropulsive LM after insertion into orbit, the extremely critical situations for CSM rescue result from anytime lift-offs with small negative phasings. In fact, for the LM in the standard orbit, a no-rescue range of phasings exists based on the maximum LM lifetime and ΔV capabilities for CSM rescue.

For situations other than these critical anytime lift-off situations, rendezvous procedures which can be accomplished within the maximum LM lifetime and ΔV capabilities and which utilize mainly onboard solutions are applicable. Also, for the majority of these situations which normally require less than maximum capabilities, extremely time-critical procedures which effect rendezvous within about 3 to 4 hours of abort are applicable although not operationally desirable. However, an anytime lift-off should be used only when it is not possible to wait for desired phasing.

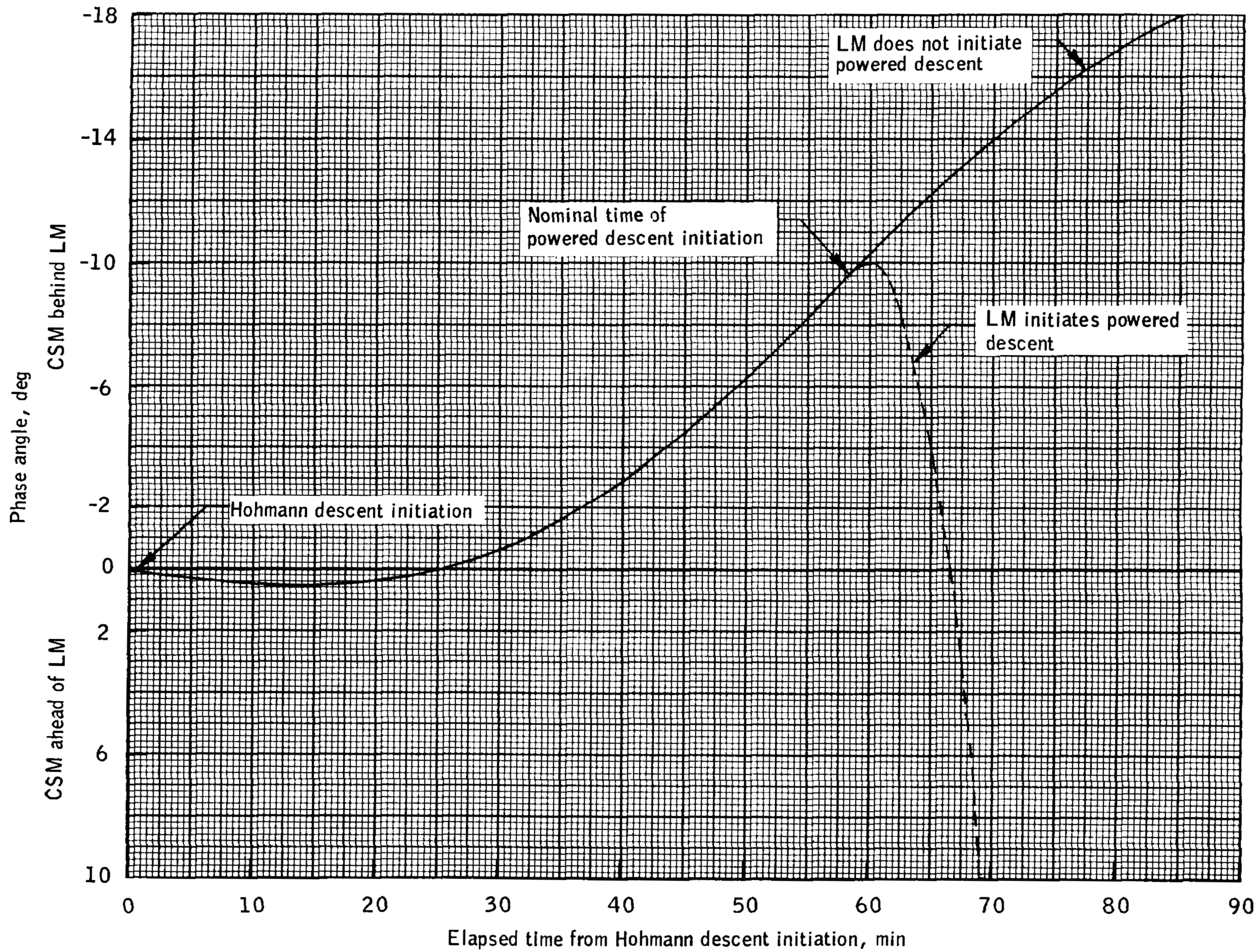


Figure 1.- Phase-angle profile for the descent phase.

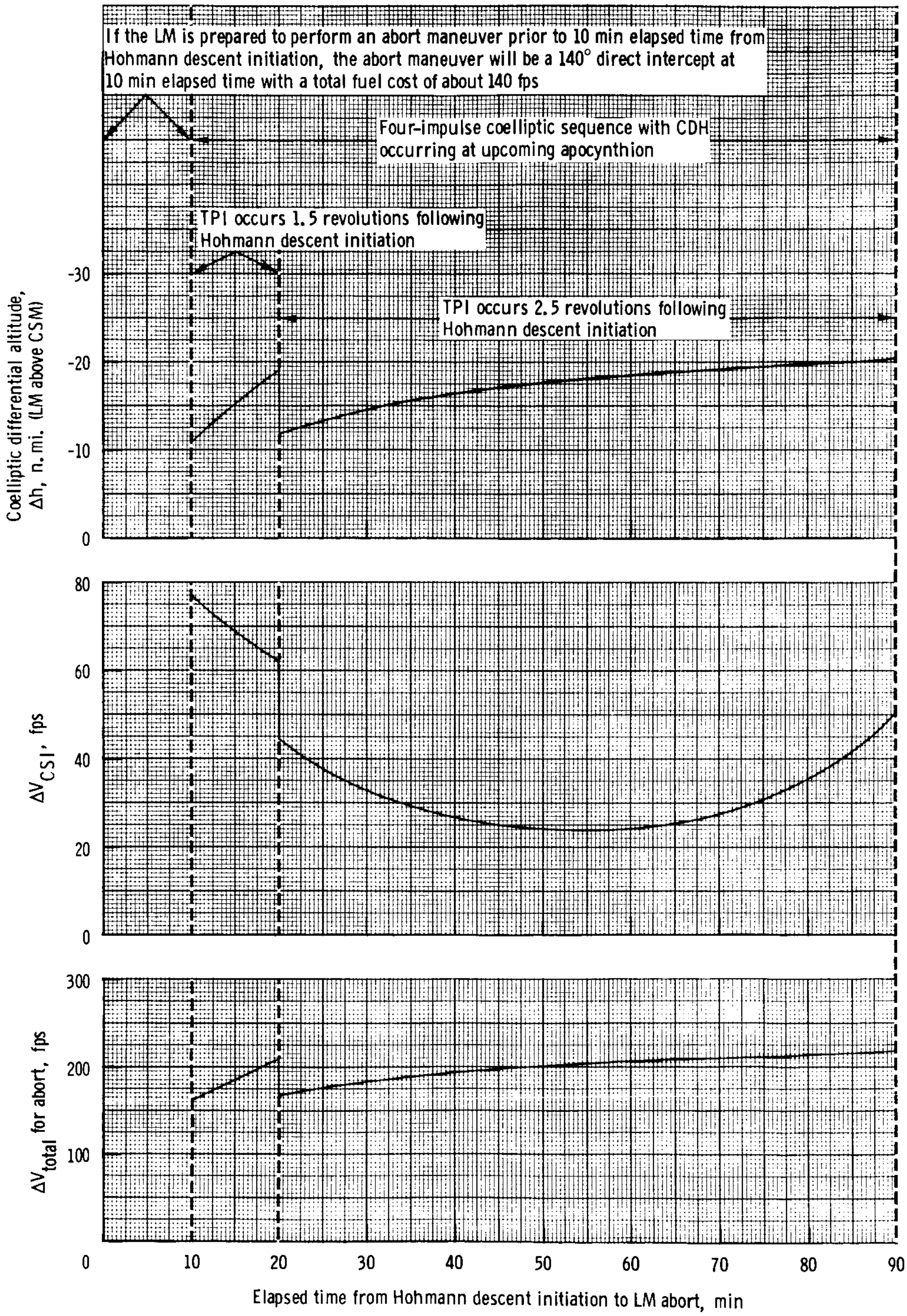


Figure 2. - Summary of recommended procedures for non-time-critical LM aborts from Hohmann descent.

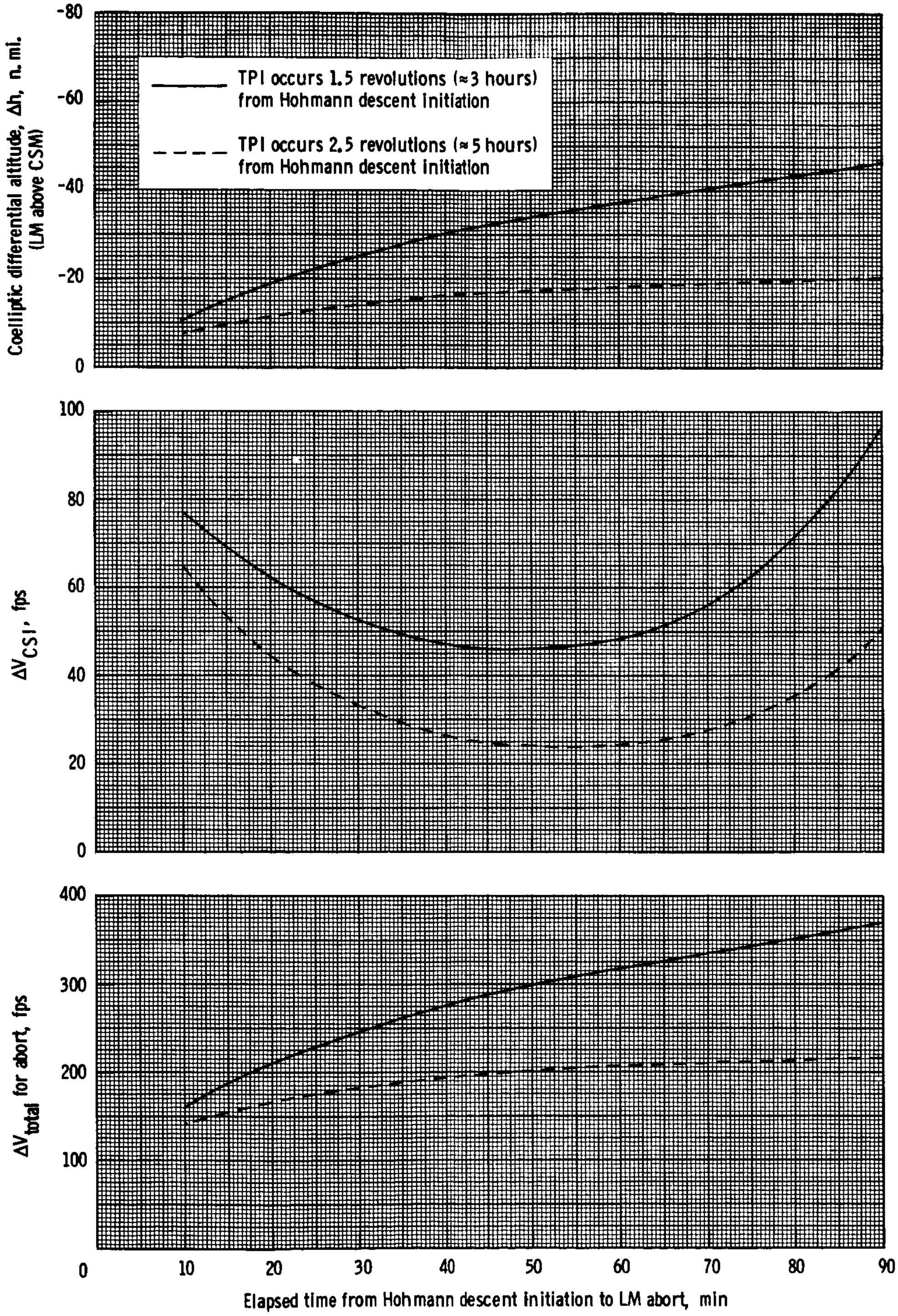
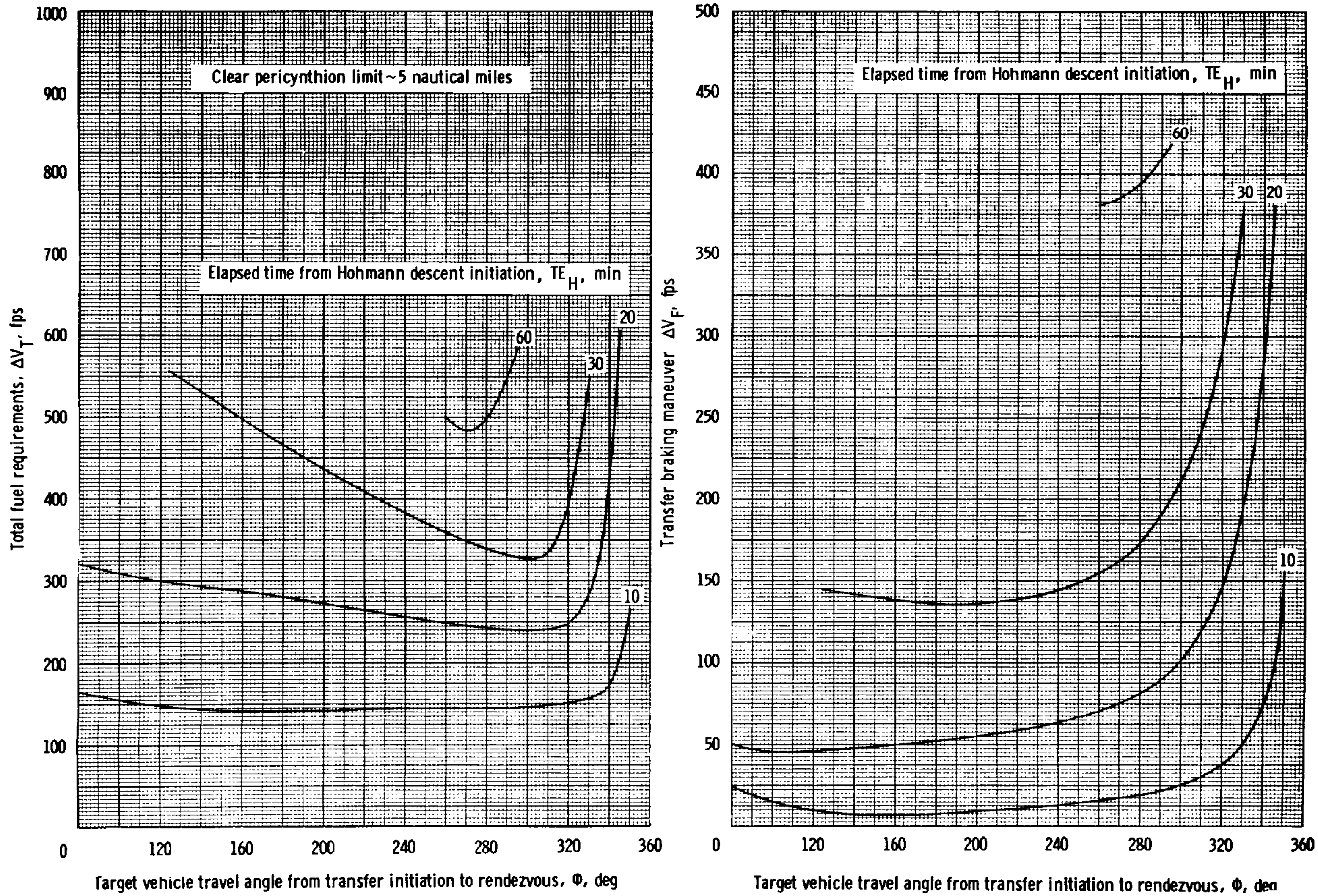


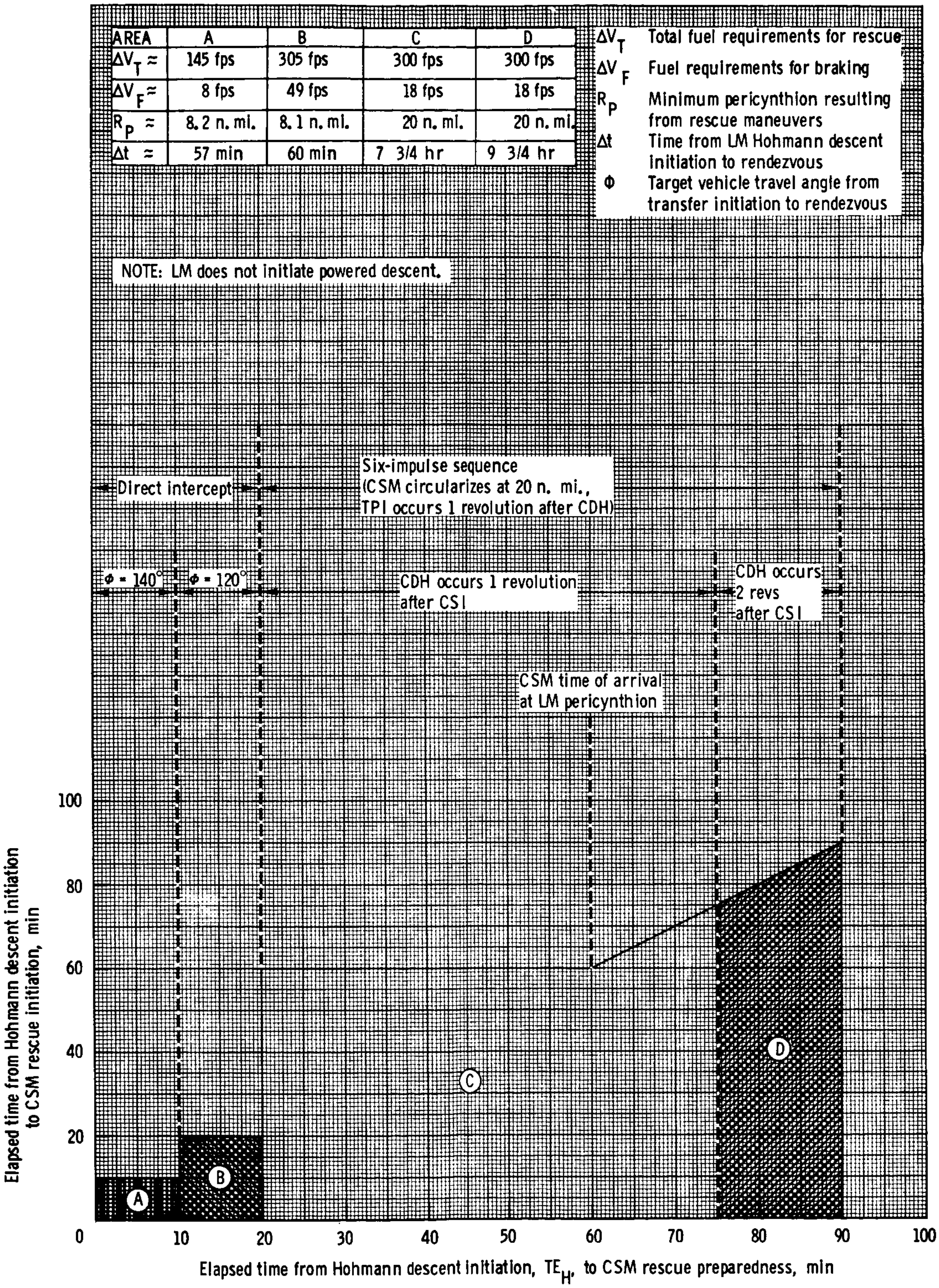
Figure 3. - LM rendezvous capabilities after LM abort from Hohmann descent utilizing four-impulse coelliptic sequence with CDH occuring at upcoming apocynthion.



(a) Total fuel requirements, ΔV_T, fps.

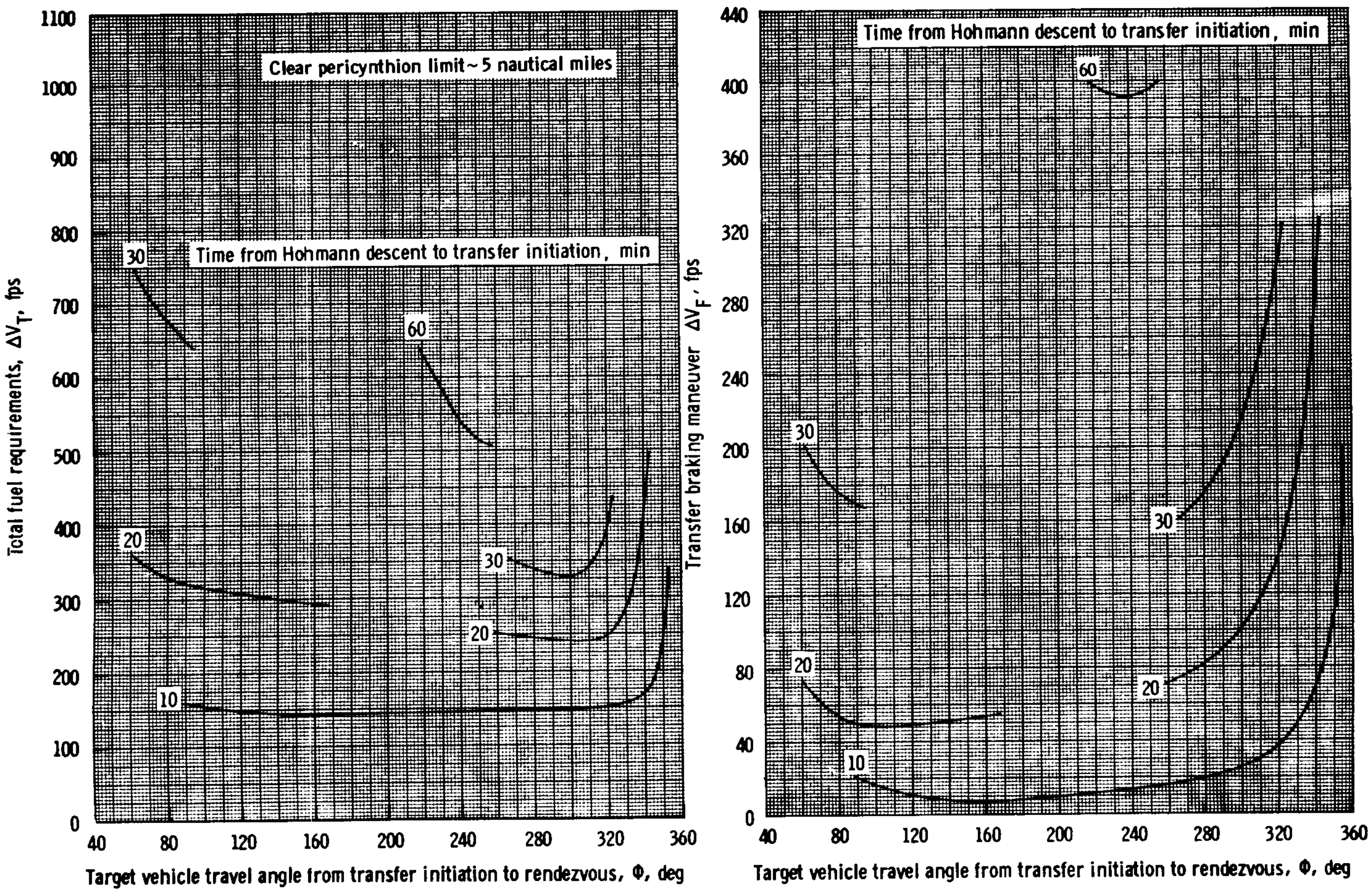
(b) Transfer braking maneuver ΔV_F, fps.

Figure 4.- LM direct-intercept capabilities from Hohmann descent orbit.



AREA	A	B	C	D
$\Delta V_T \approx$	145 fps	305 fps	300 fps	300 fps
$\Delta V_F \approx$	8 fps	49 fps	18 fps	18 fps
$R_P \approx$	8.2 n. mi.	8.1 n. mi.	20 n. mi.	20 n. mi.
$\Delta t \approx$	57 min	60 min	7 3/4 hr	9 3/4 hr

Figure 5. - Summary of recommended procedures for non-time-critical CSM rescue during Hohmann descent.



(a) Total fuel requirements, ΔV_T, fps.

(b) Transfer braking maneuver ΔV_F, fps.

Figure 6. - CSM direct-intercept rescue capabilities of an inactive LM in Hohmann descent orbit.

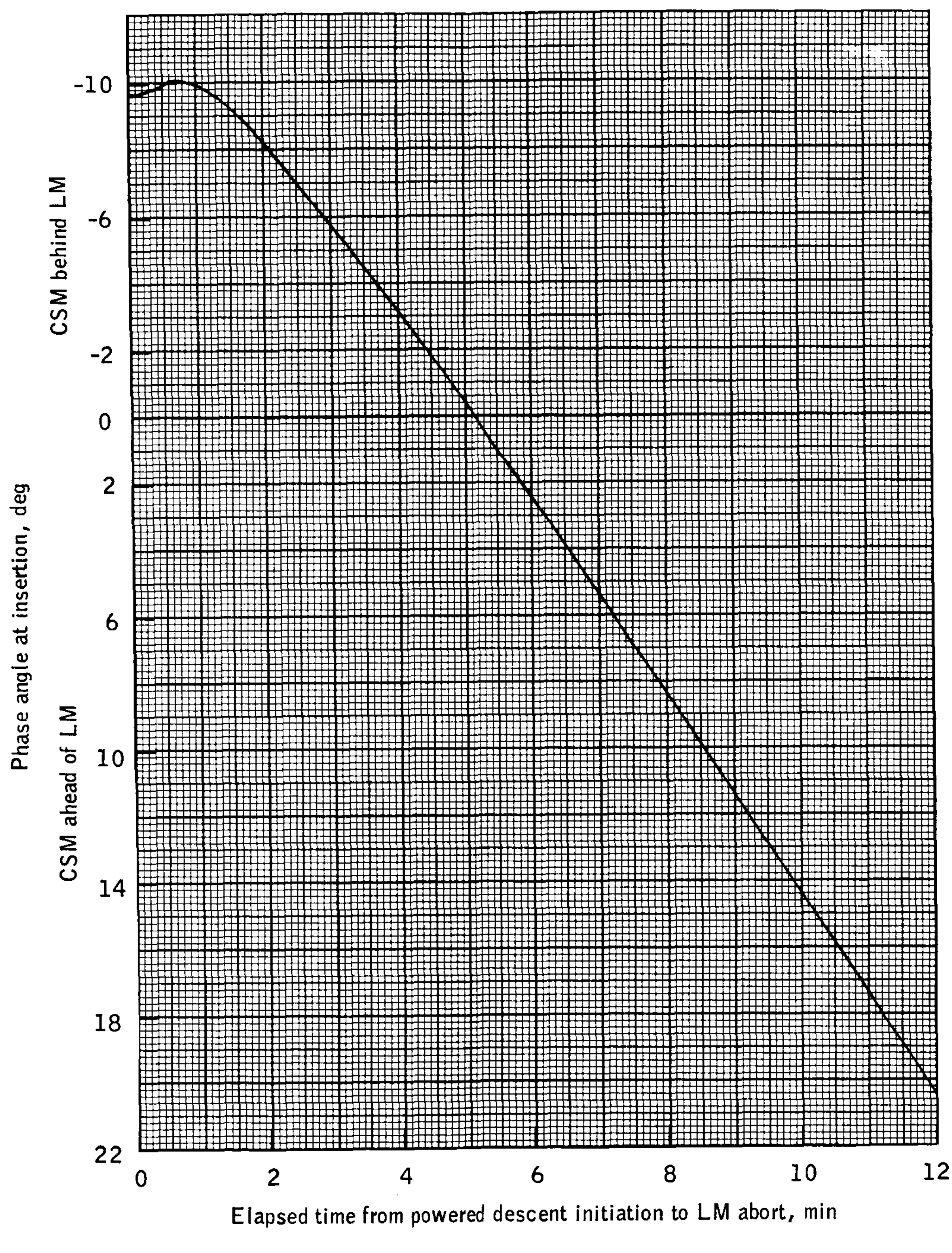


Figure 7.- Phase-angle profile resulting from LM abort during powered descent.

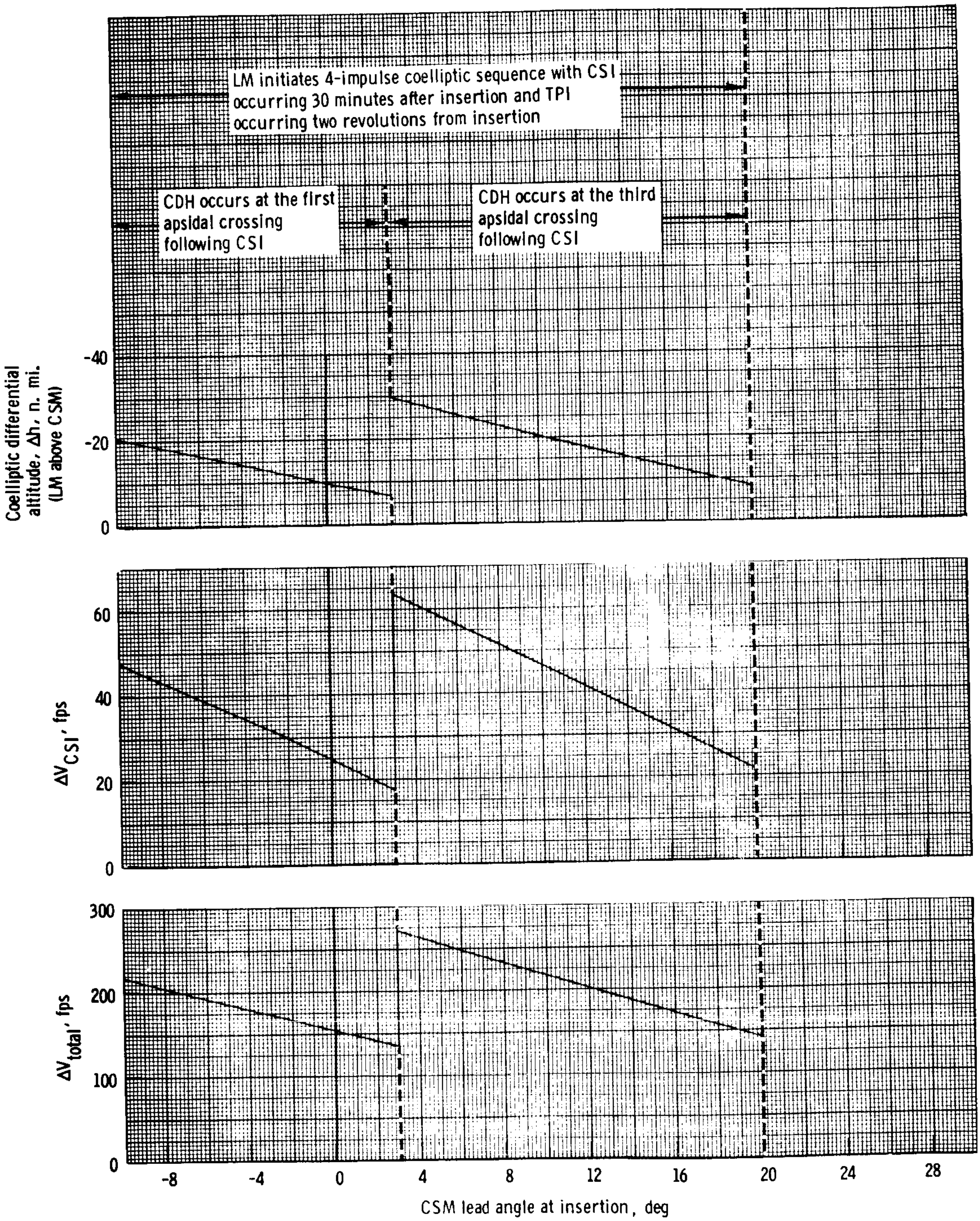


Figure 8. - Summary of recommended procedures for non-time-critical, LM-active aborts from powered descent.

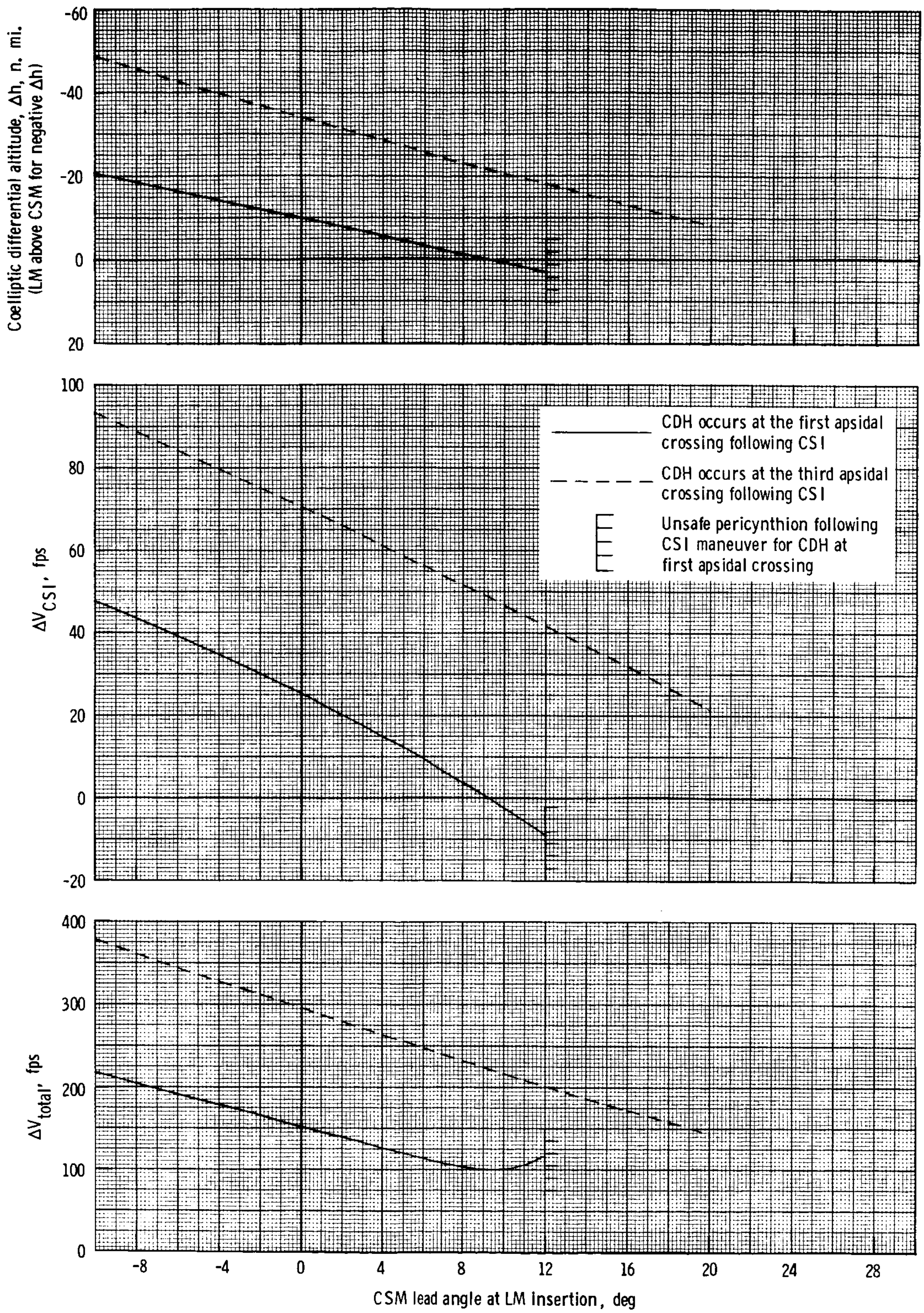
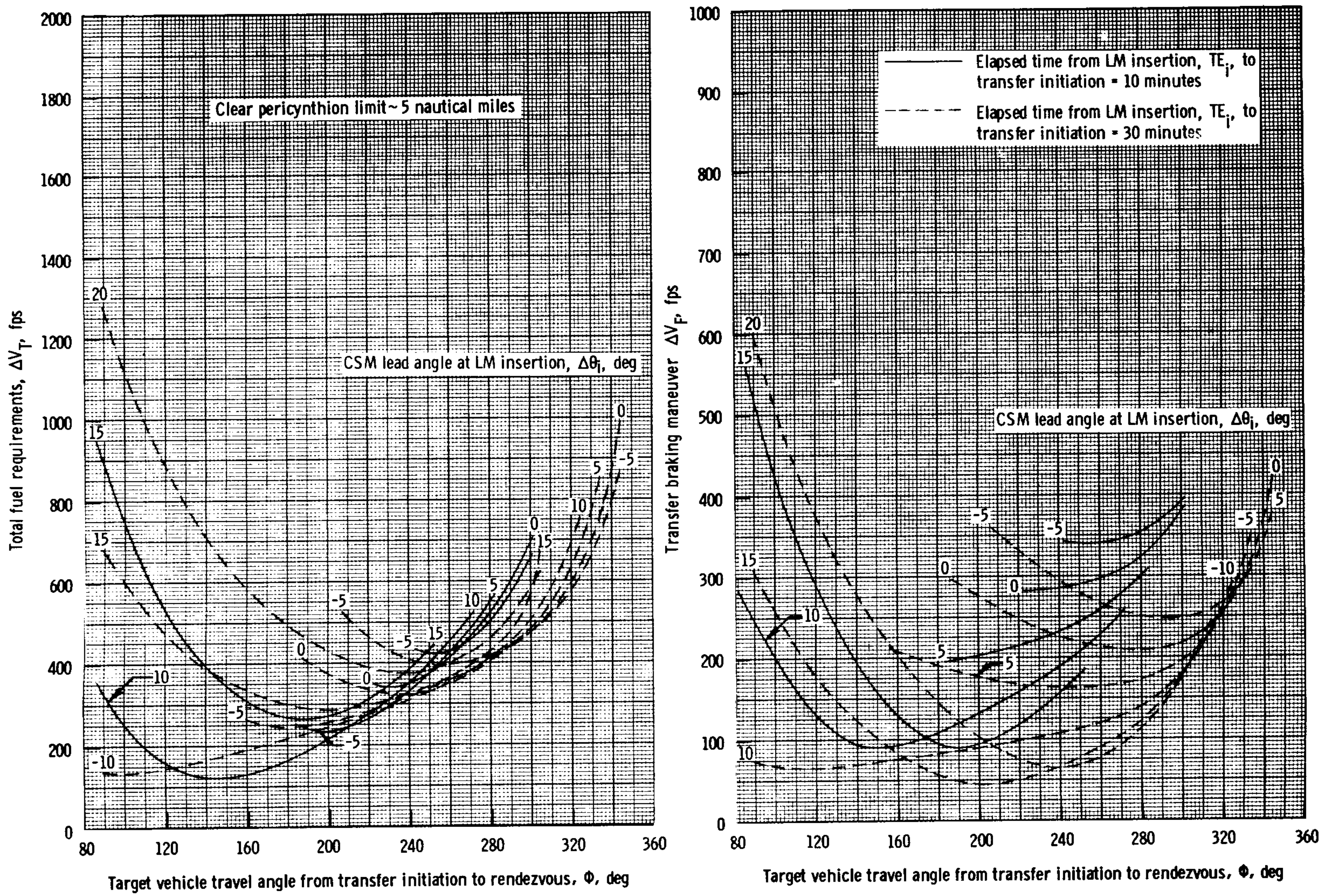


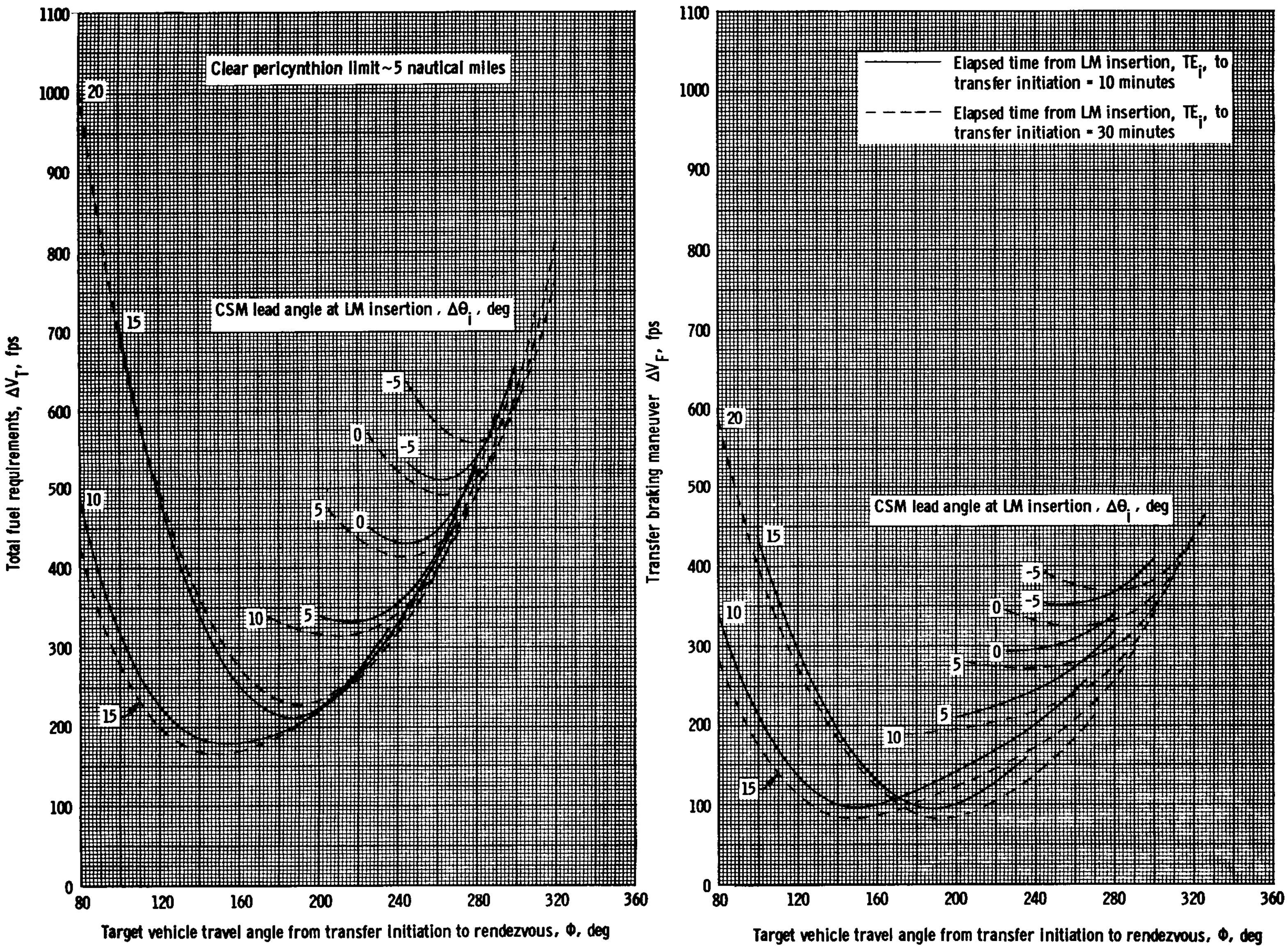
Figure 9.- LM rendezvous capabilities after LM abort from powered descent utilizing the four-impulse coelliptic sequence with CSI 30 minutes from insertion and TPI two revolutions from insertion.



(a) Total fuel requirements, ΔV_T, fps.

(b) Transfer braking maneuver ΔV_F, fps.

Figure 10.- LM direct intercept capabilities from 80/10 nautical-mile orbit.



(a) Total fuel requirements, ΔV_T, fps.

(b) Transfer braking maneuver ΔV_F, fps.

Figure 11.- LM direct intercept capabilities from 30/10 nautical-mile orbit.

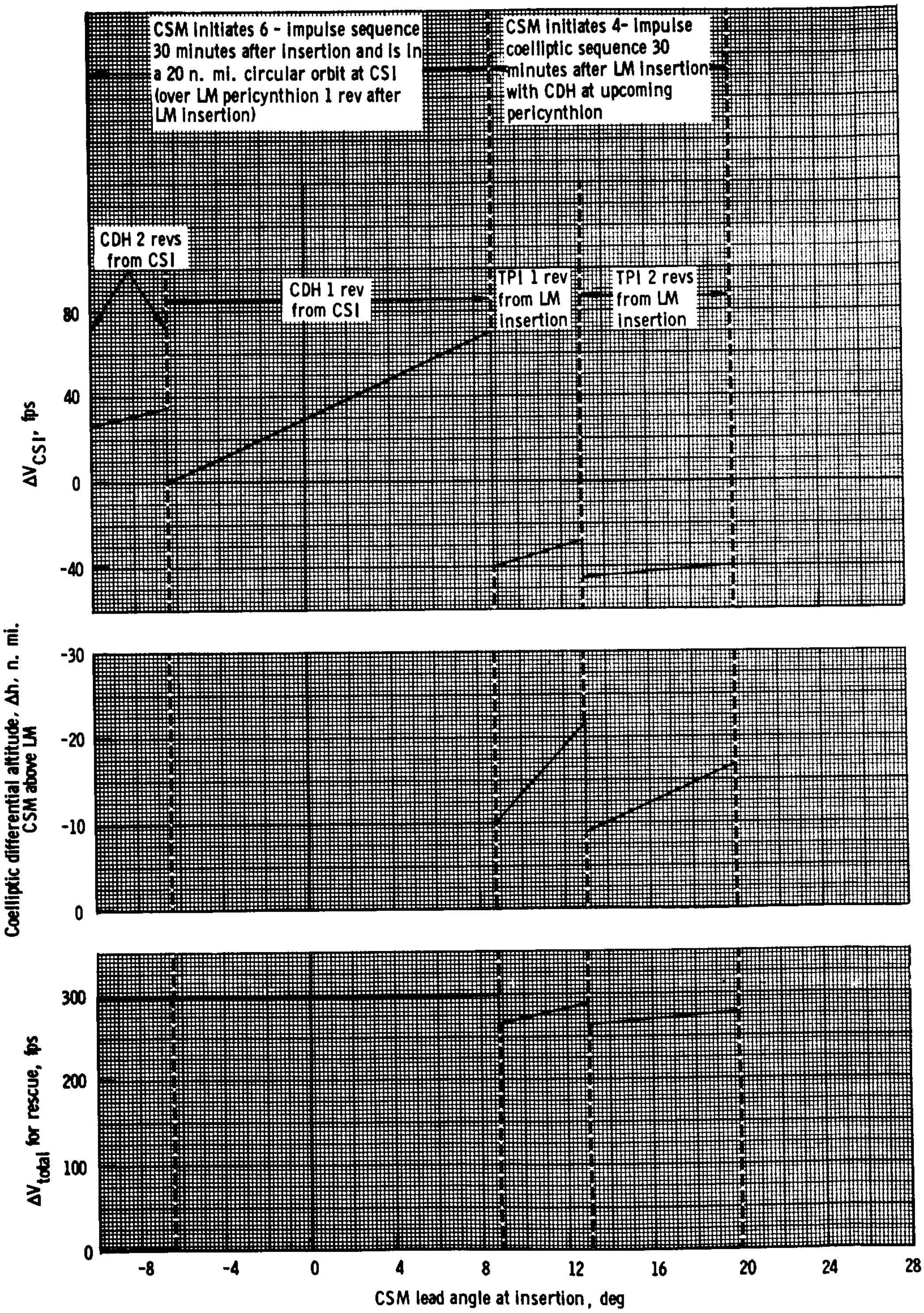


Figure 12. - Summary of recommended procedures for non-time-critical CSM rescue after LM abort from powered descent.

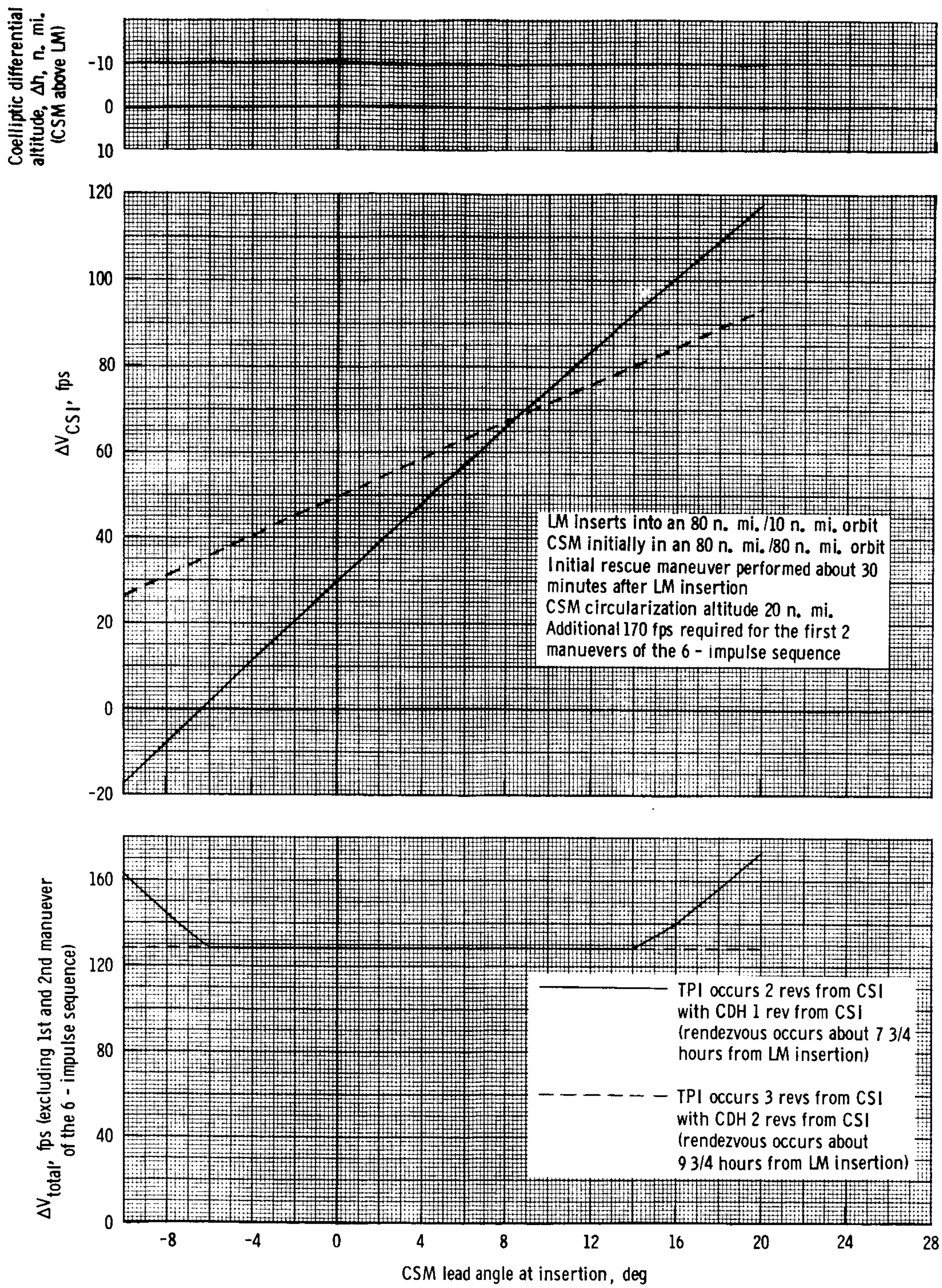


Figure 13. - CSM rescue capabilities utilizing the six-impulse sequence after LM aborts from powered descent.

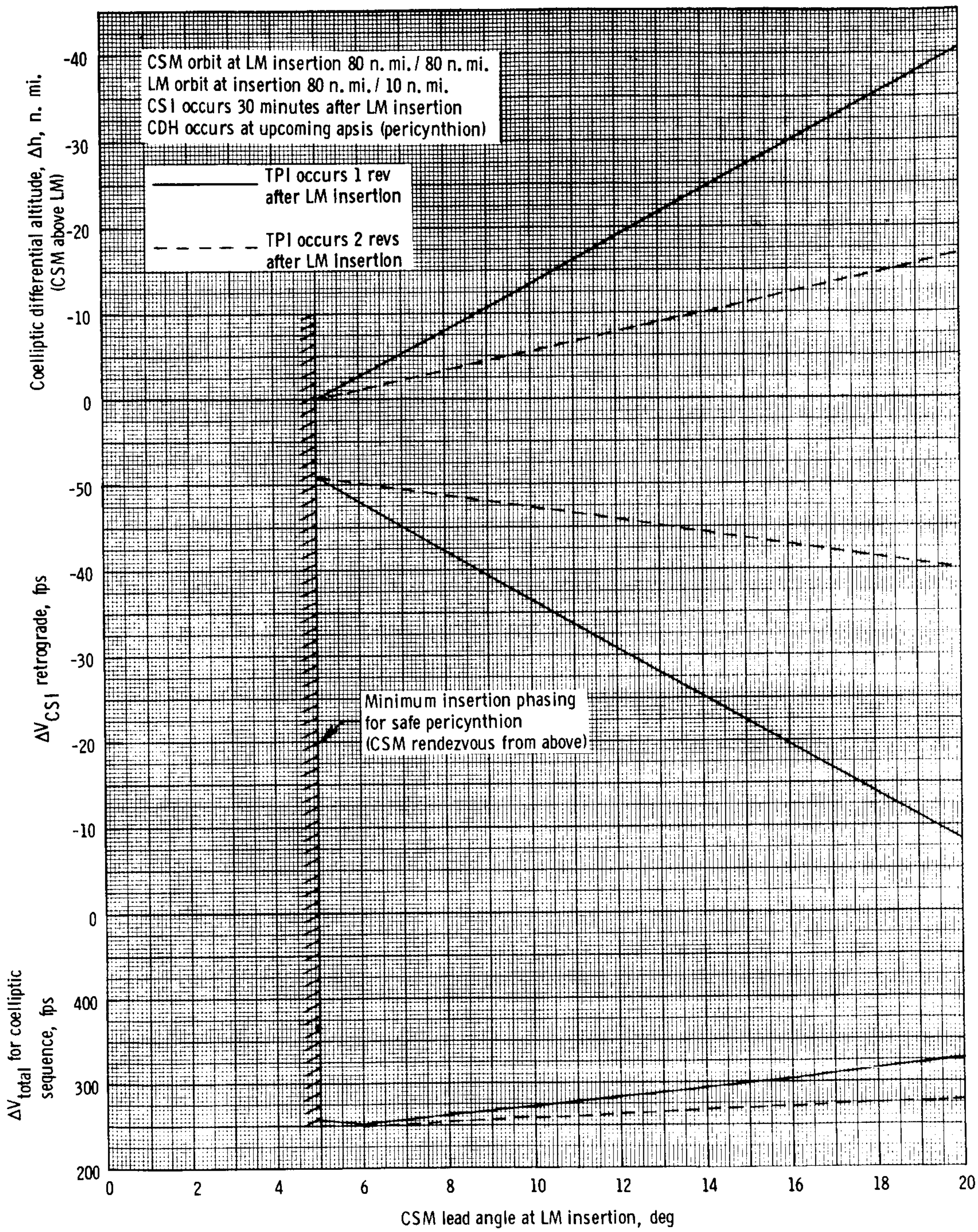
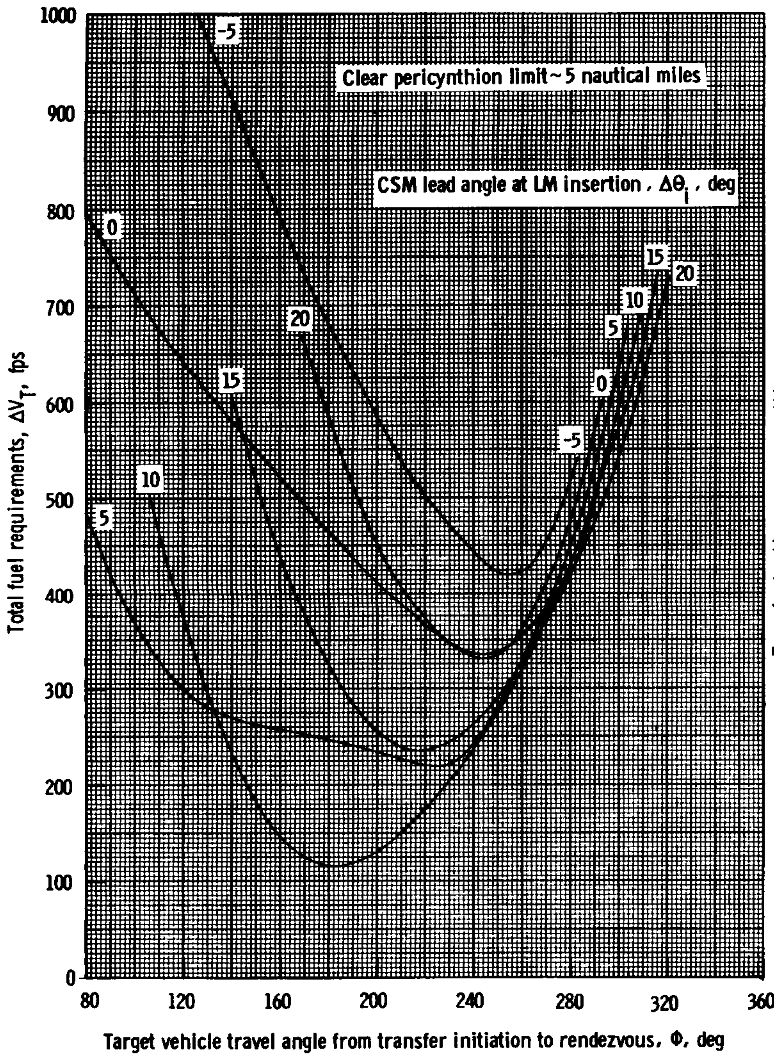
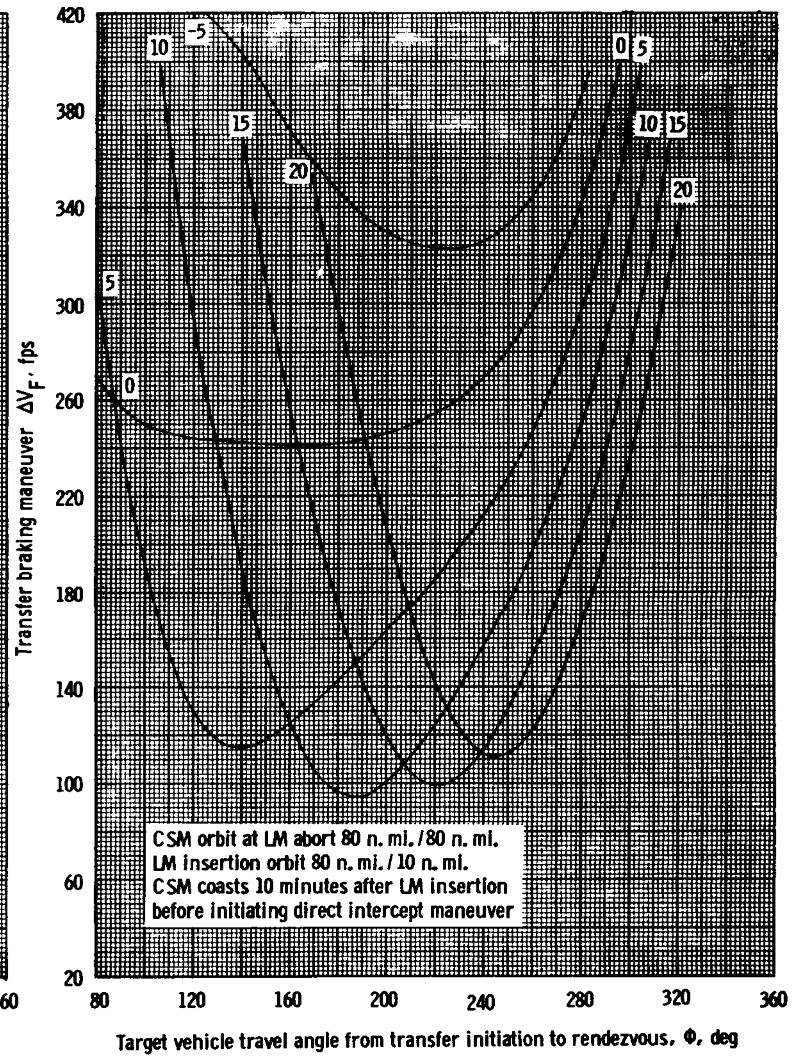


Figure 14. - CSM rescue capabilities of an inactive LM utilizing four-impulse coelliptic sequence after LM aborts during powered descent.



(a) Total fuel requirements, ΔV_T, fps.



(b) Transfer braking maneuver ΔV_F, fps.

Figure 15. - CSM direct intercept rescue capabilities of an inactive LM after LM aborts from powered descent.

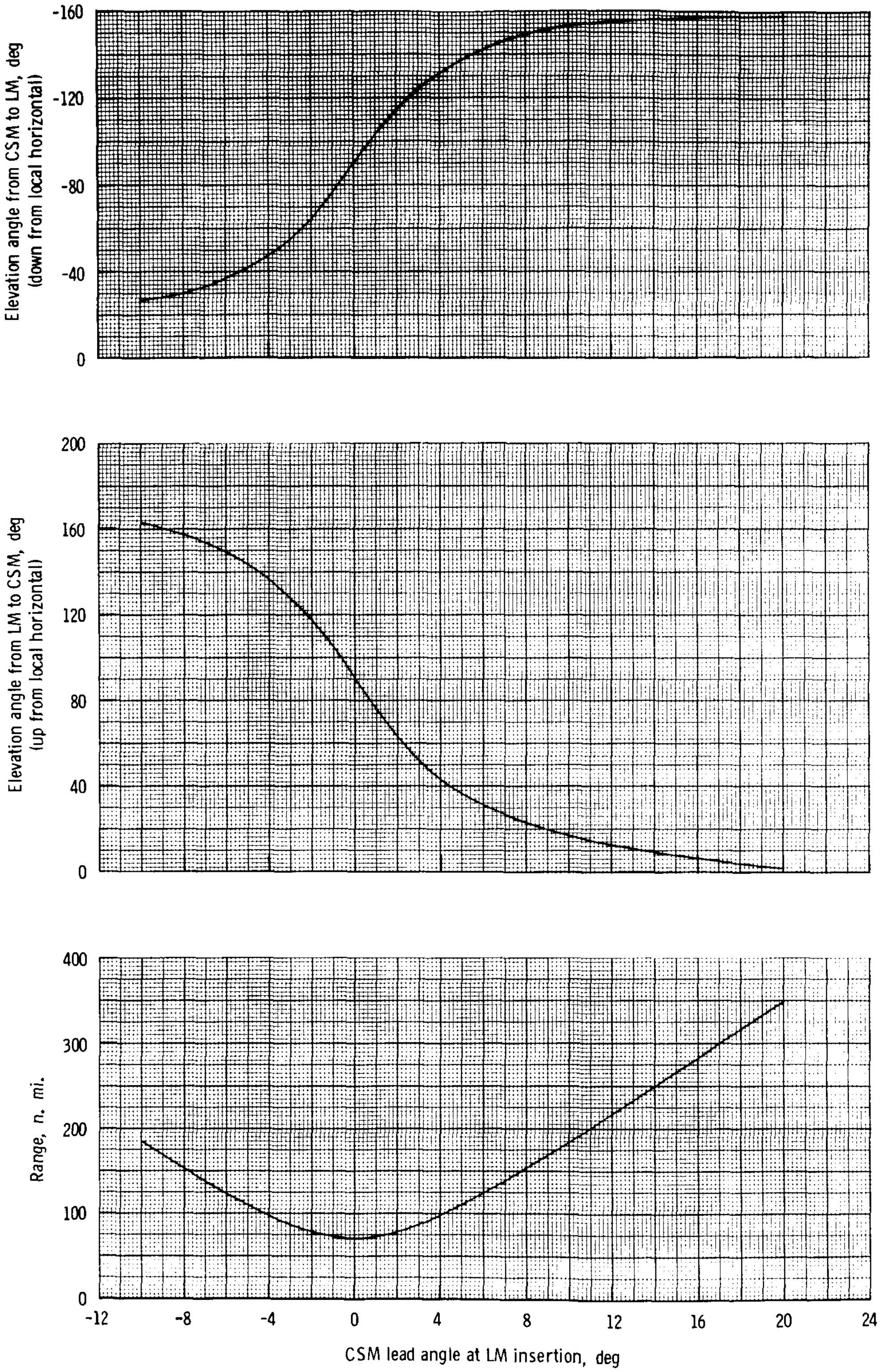


Figure 16. - Relative parameters between LM and CSM at LM insertion into orbit from an abort during powered descent.

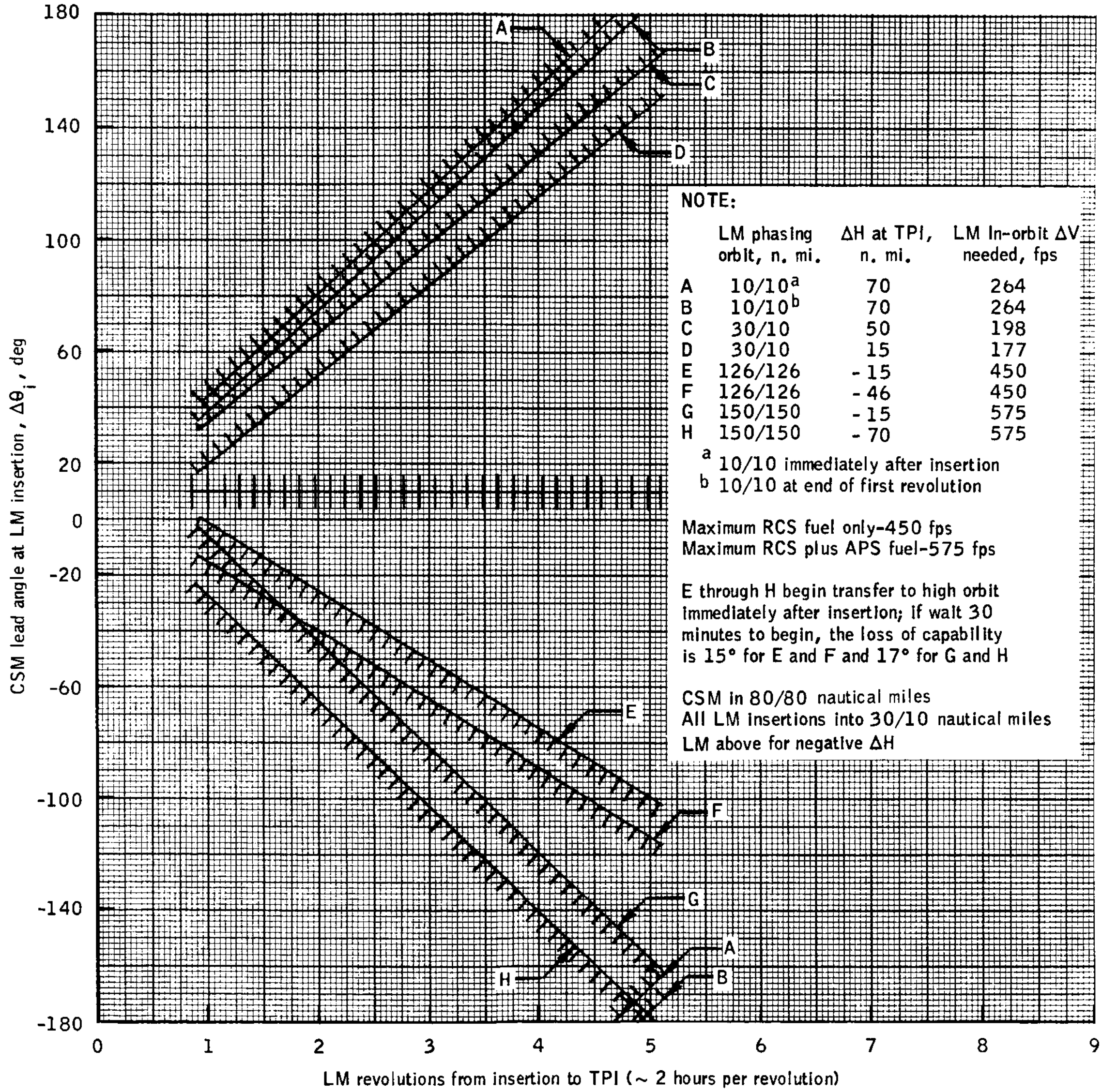


Figure 17.- LM-alone capabilities associated with anytime lift-off.

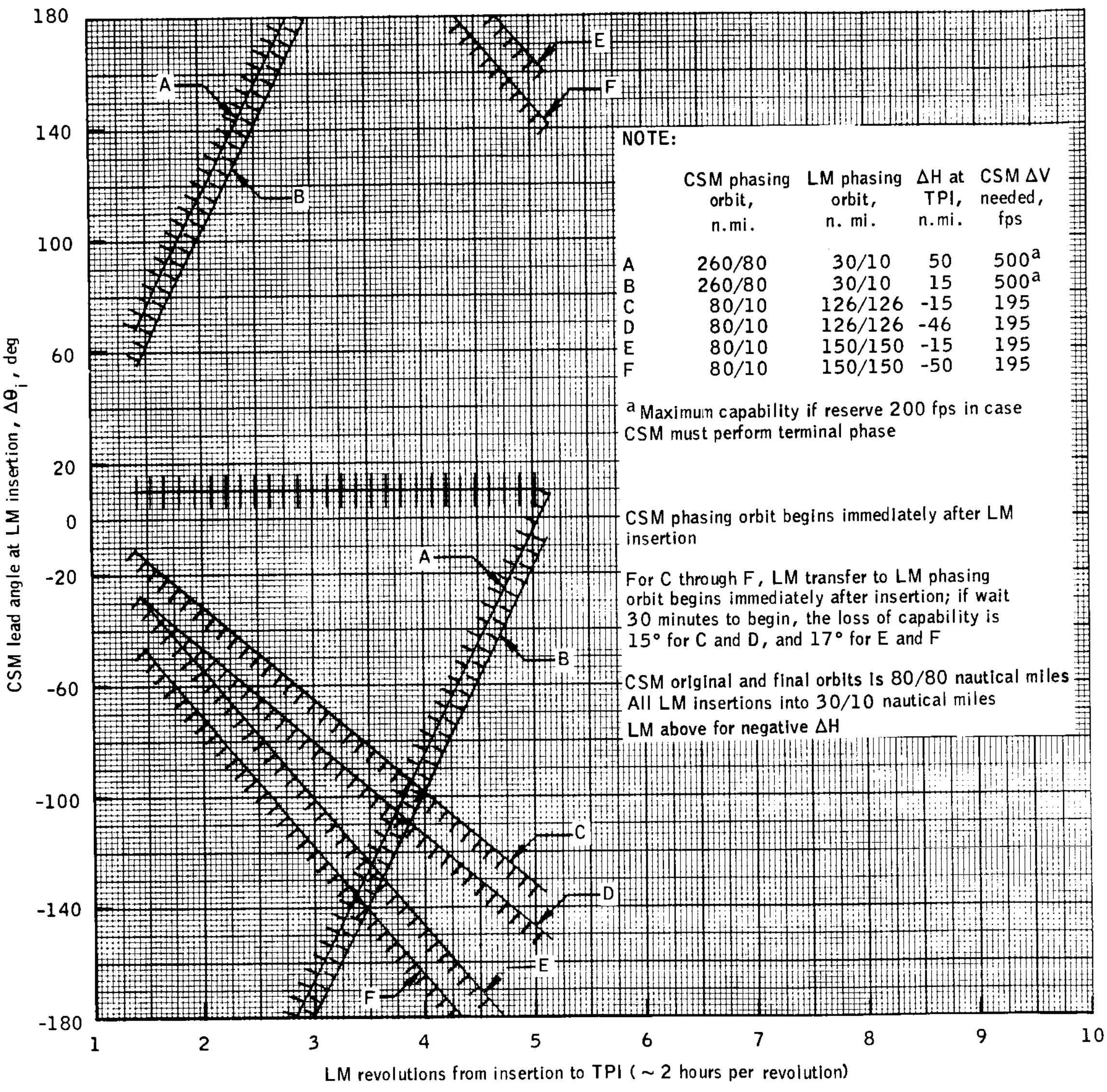


Figure 18.- CSM-assist capabilities associated with anytime lift-off.

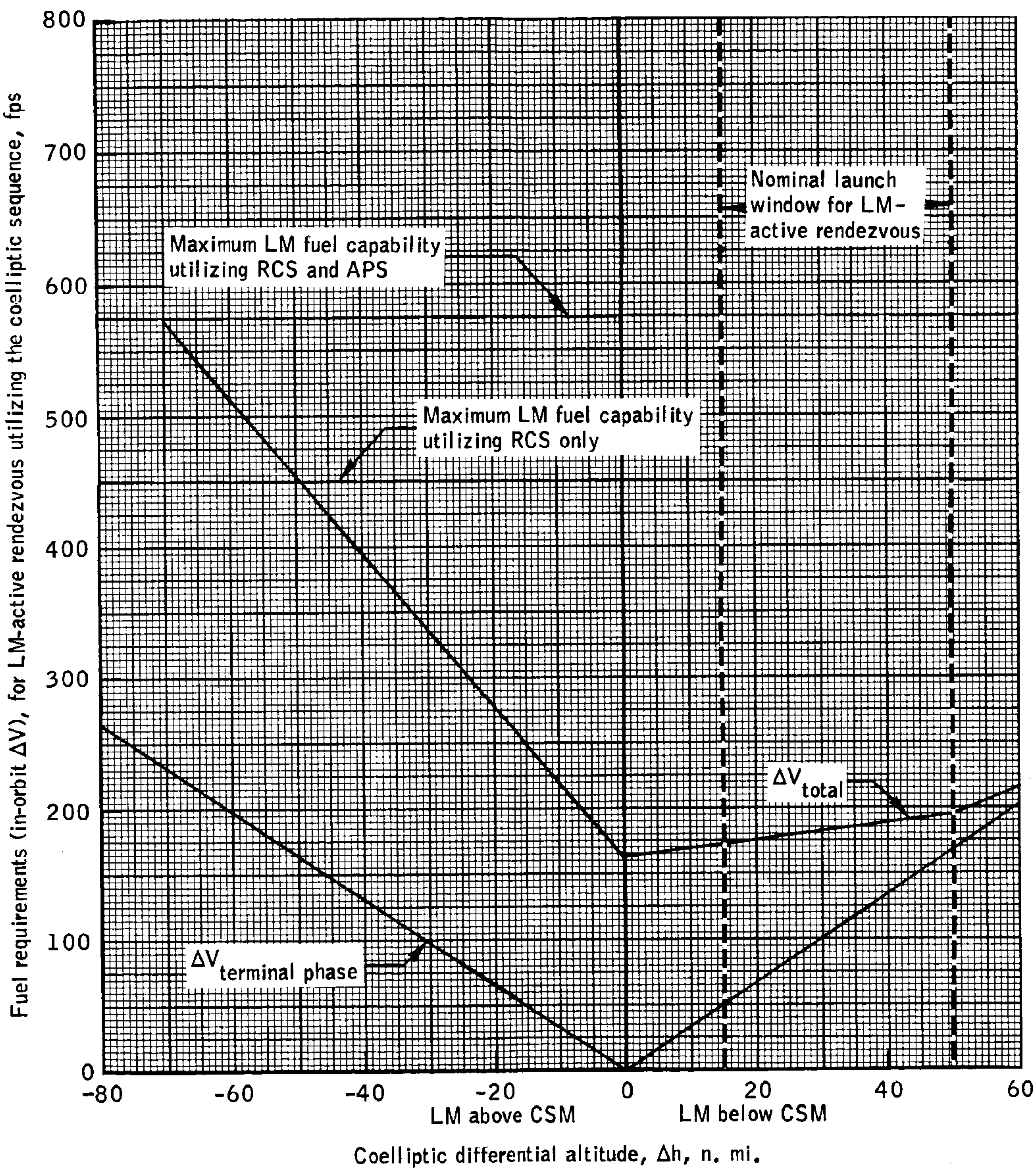


Figure 19.- ΔV requirements for a LM-active rendezvous utilizing the coelliptic sequence if ascent from surface and insertion into the standard orbit.

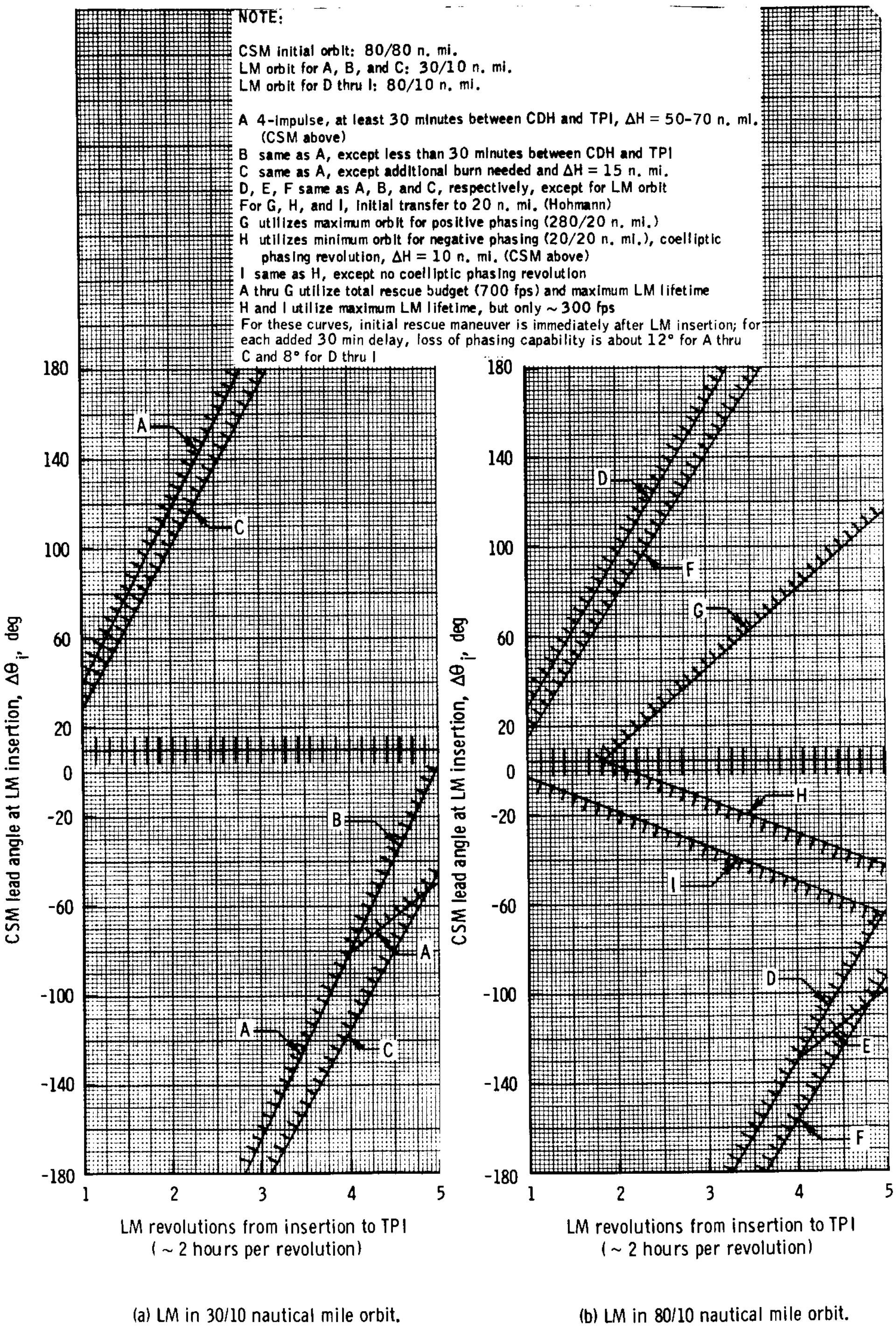


Figure 20. - CSM rescue capabilities.

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3. Alexander, James D. and Bell, Jerome A.: Parametric Study Of Coelliptic CSM Rescue of A LM That Is Non-Propulsive After Anytime Insertion Into The Standard Ascent Orbit For AS-504A. MSC IN 66-FM-133, November 9, 1966.

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UNITED STATES GOVERNMENT

Memorandum

NASA-Manned Spacecraft Center
Mission Planning & Analysis Division

TO : See attached list

DATE: 9 MAY 1967

File No. 67-FM13-169

FROM : FM13/Chief, Apollo Trajectory Support Office

SUBJECT: Spacecraft Preliminary Abort and Alternate Mission Studies for AS-504, Volume III, Lunar Orbit Phase LM Abort and CSM Rescue

67-FM-13-169

The attached document presents the results of LM abort and CSM rescue studies for the lunar orbit phase of a lunar landing mission. Included are preliminary recommendations for LM abort and CSM rescue procedures. This information will provide a basis for initial associated analyses and planning. It is emphasized that subsequent analyses are dependent on some presently undefined ground rules. This document should be thoroughly evaluated in terms of hardware, software, flight control and crew procedures, and all other implementation procedures. It is requested that this document be reviewed and comments be returned to this division. All recommendations, constraints, and general comments should be included.

Volume II of the Preliminary Abort and Alternate Mission Studies will contain CSM abort information. It is being prepared and will be available at a later date.

John R Gurley
for John P. Bryant

APPROVED BY:

J P Mayer
John P. Mayer
Chief, Mission Planning
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Enclosure

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